

(12) **United States Patent**  
**Rothenberg**

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(54) **METHOD OF LOCATING THE TIP OF A CENTRAL VENOUS CATHETER**

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(71) Applicant: **Bard Access Systems, Inc.**, Salt Lake City, UT (US)

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(72) Inventor: **Peter M. Rothenberg**, Petaluma, CA (US)

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(73) Assignee: **Bard Access Systems, Inc.**, Salt Lake City, UT (US)

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*Primary Examiner* — William Levicky

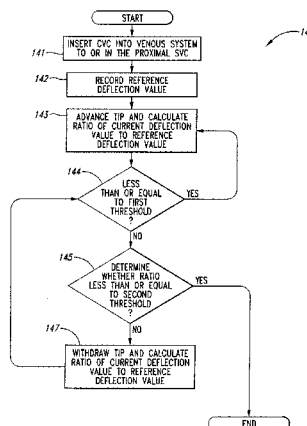
(74) *Attorney, Agent, or Firm* — Rutan & Tucker, LLP

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**ABSTRACT**

Methods of locating a tip of a central venous catheter ("CVC") relative to the superior vena cava, sino-atrial node, right atrium, and/or right ventricle using electrocardiogram data. The CVC includes at least one electrode. In particular embodiments, the CVC includes two or three pairs of electrodes. Further, depending upon the embodiment implemented, one or more electrodes may be attached to the patient's skin. The voltage across the electrodes is used to generate a P wave. A reference deflection value is determined for the P wave detected when the tip is within the proximal superior vena cava. Then, the tip is advanced and a new deflection value determined. A ratio of the new and reference deflection values is used to determine a tip location. The ratio may be used to instruct a user to advance or withdraw the tip.

**4 Claims, 15 Drawing Sheets**



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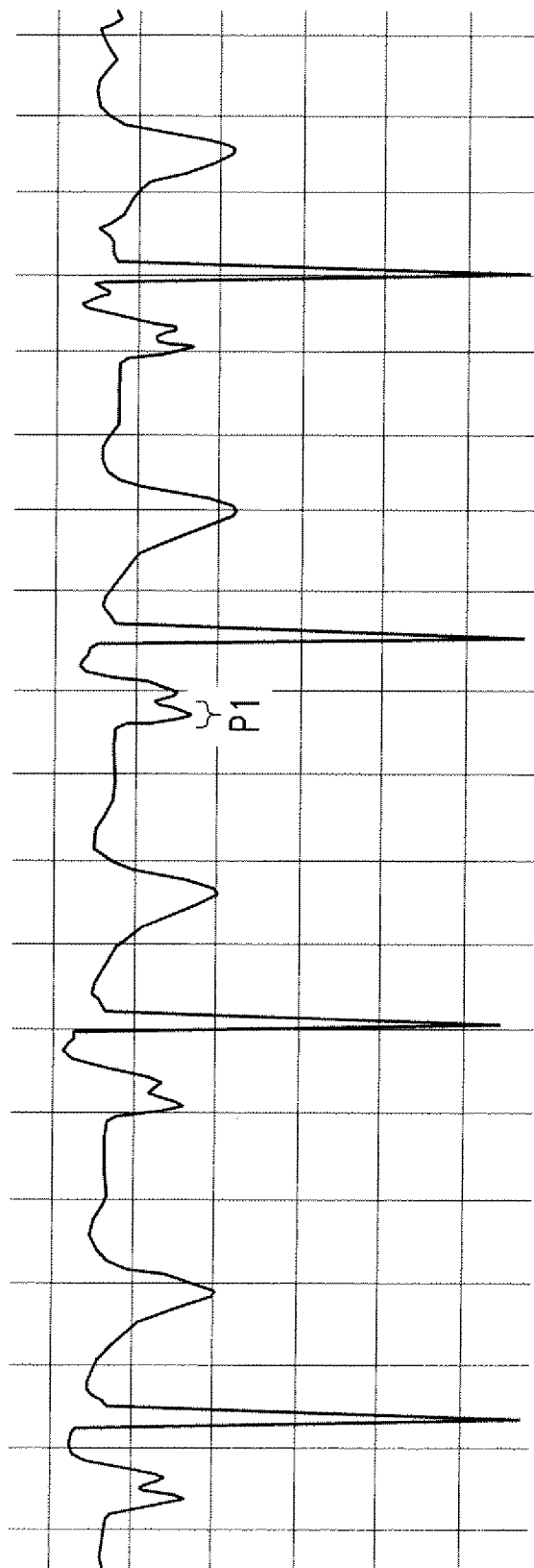
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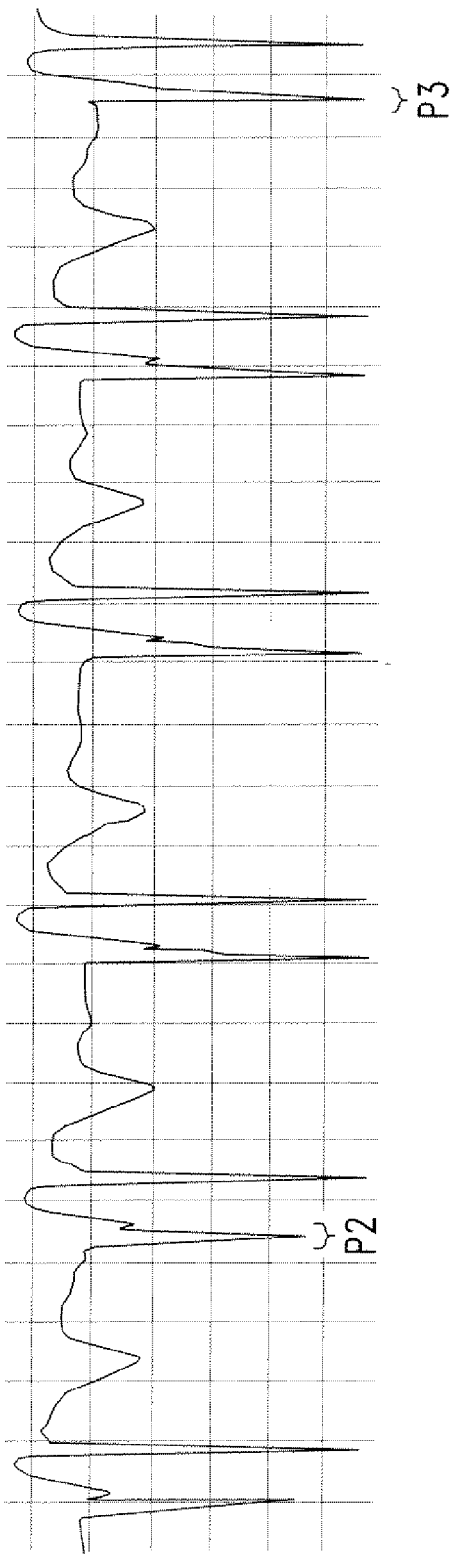
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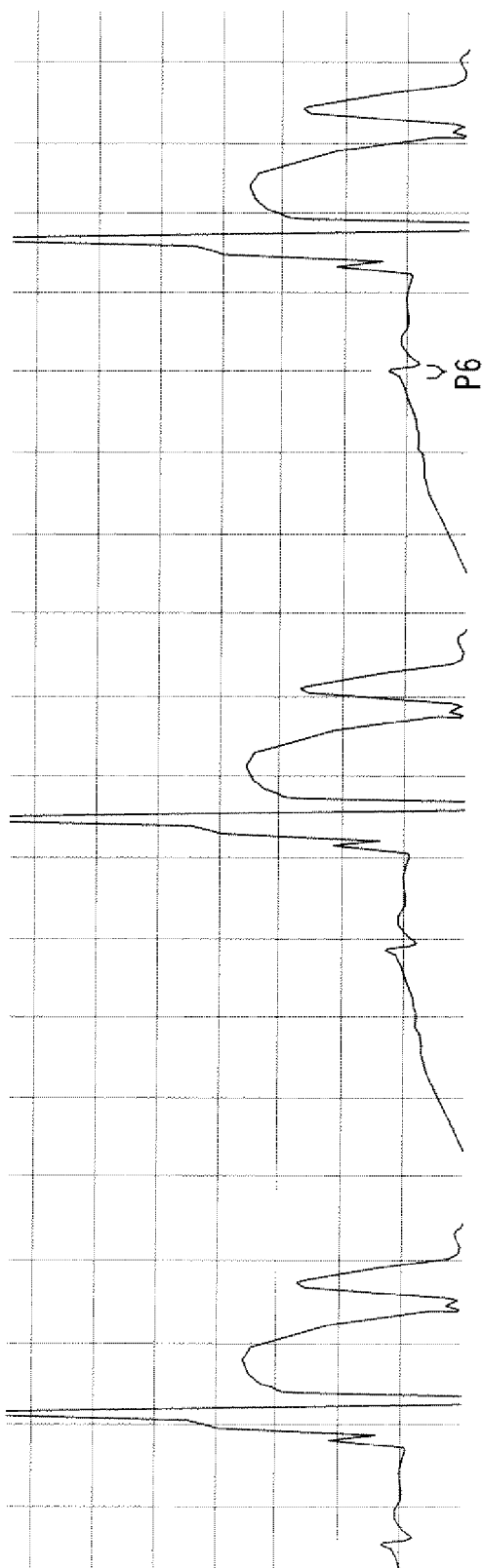
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*Fig. 1A*



*Fig. 1B*



*Fig. 1C*

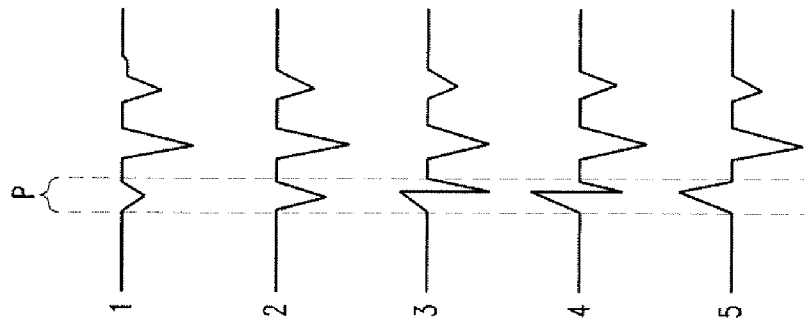


Fig. 2B

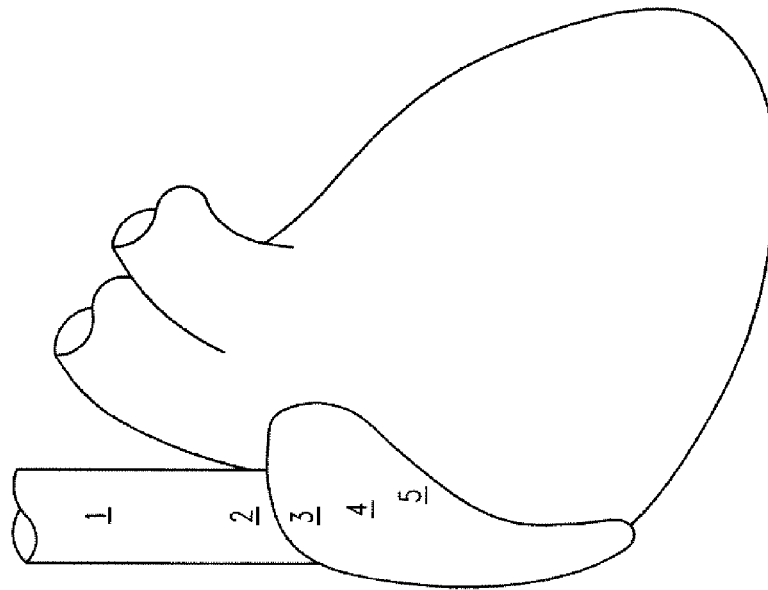


Fig. 2A

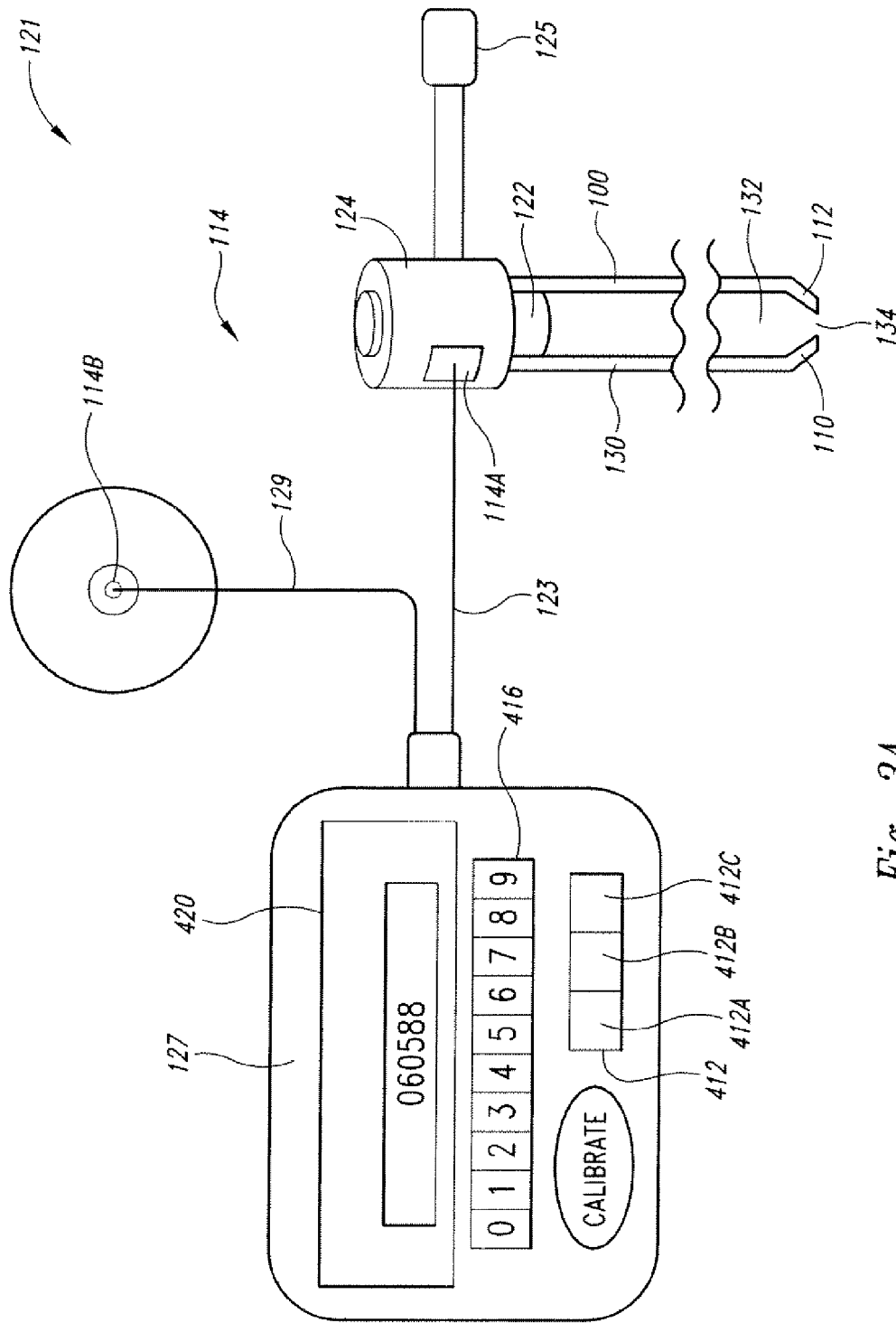


Fig. 3A



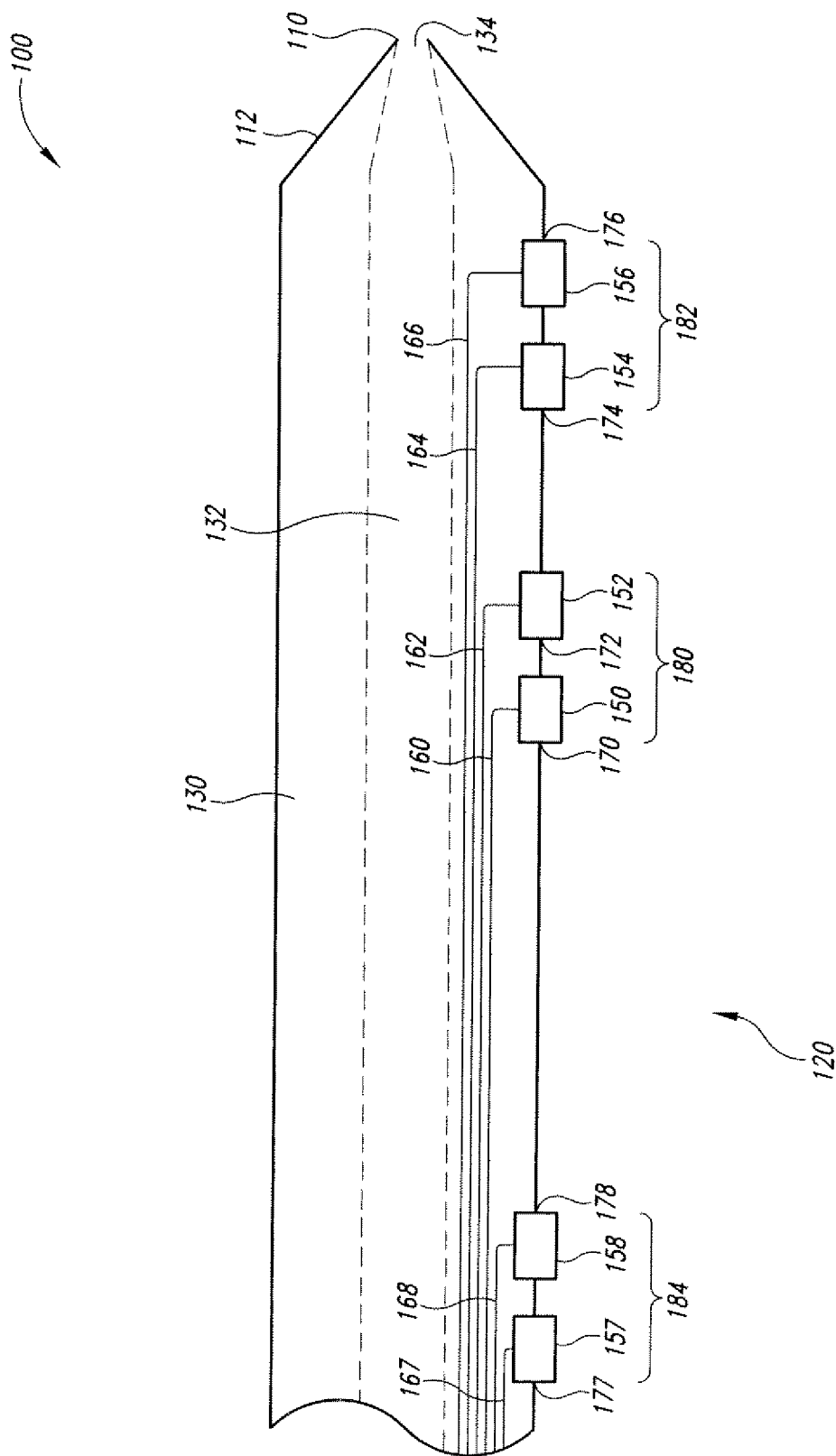
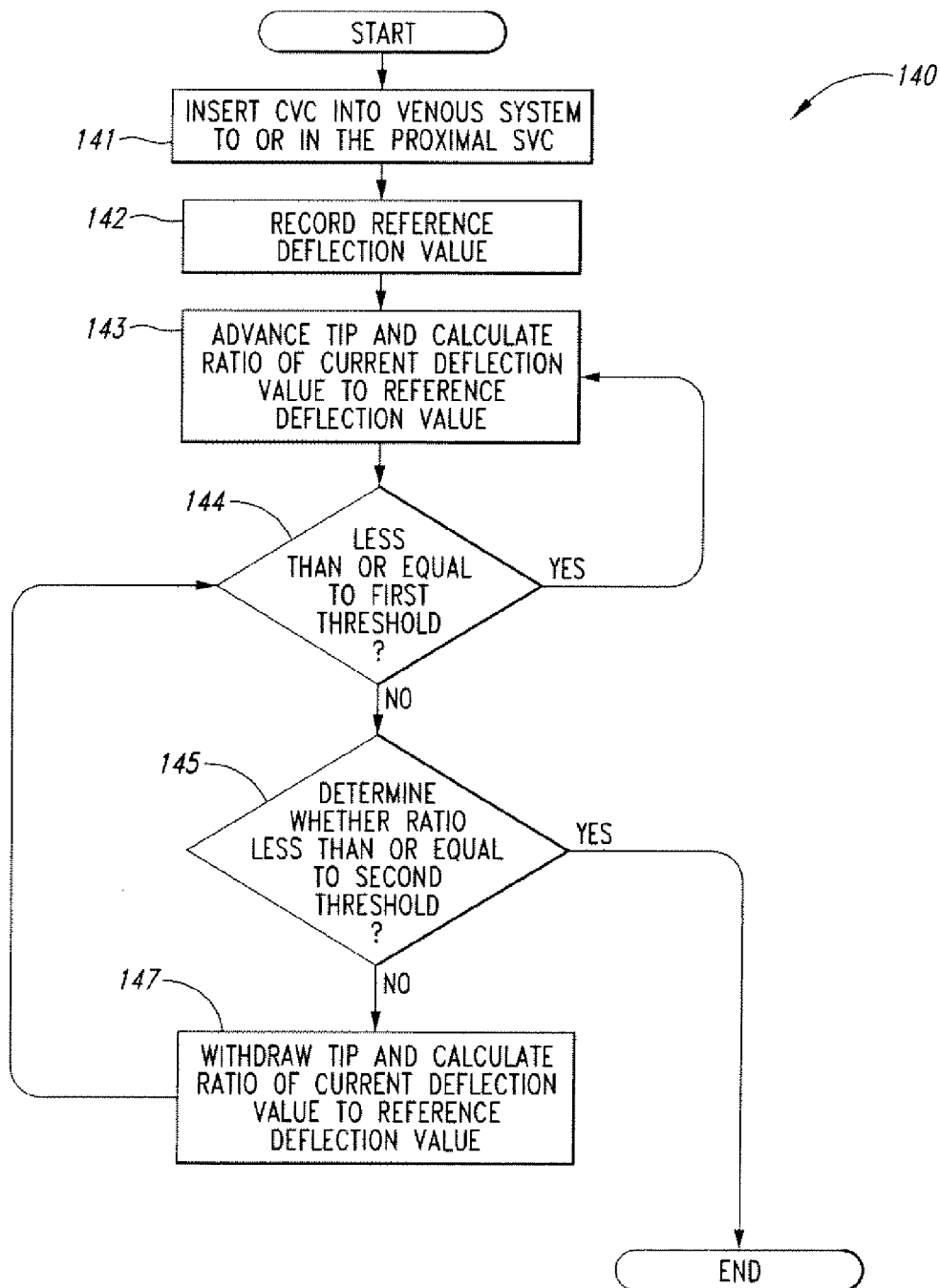
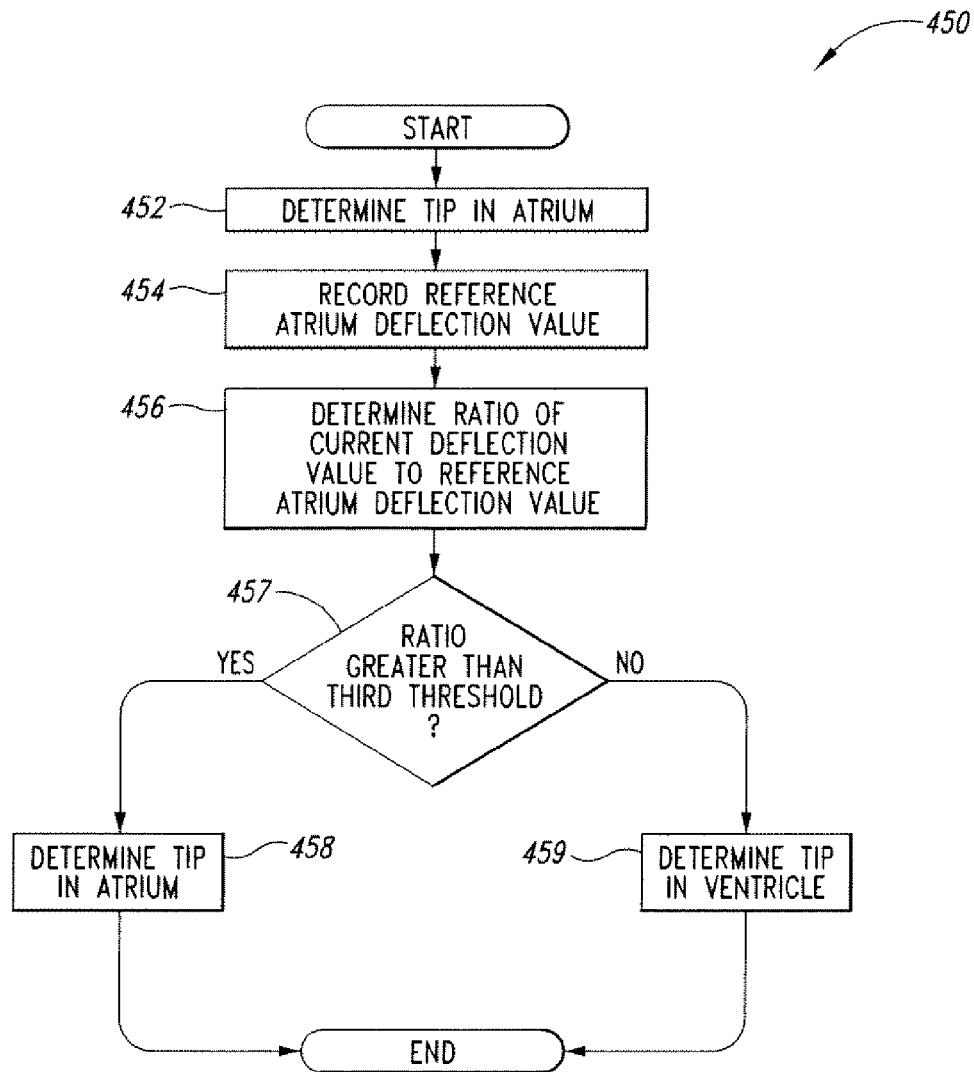
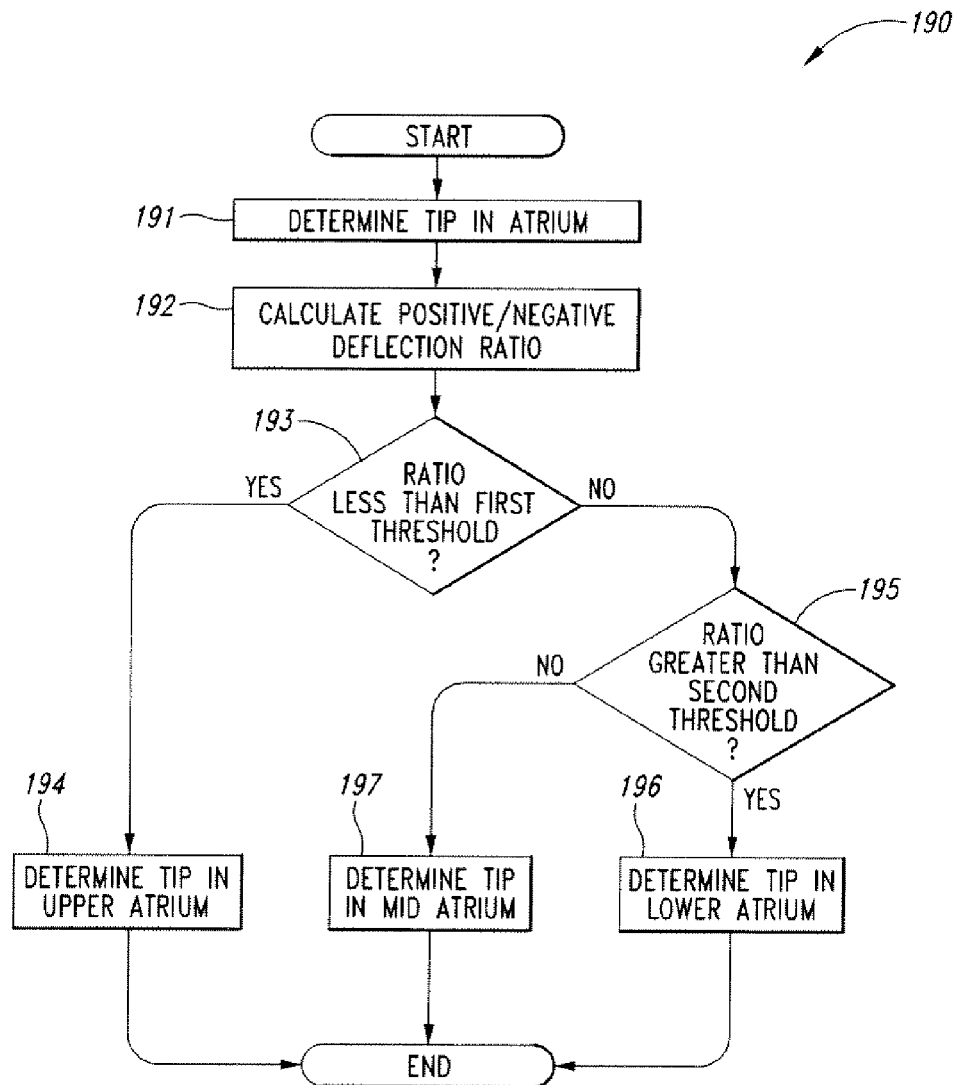


Fig. 3B

*Fig. 4*

*Fig. 5*

*Fig. 6*

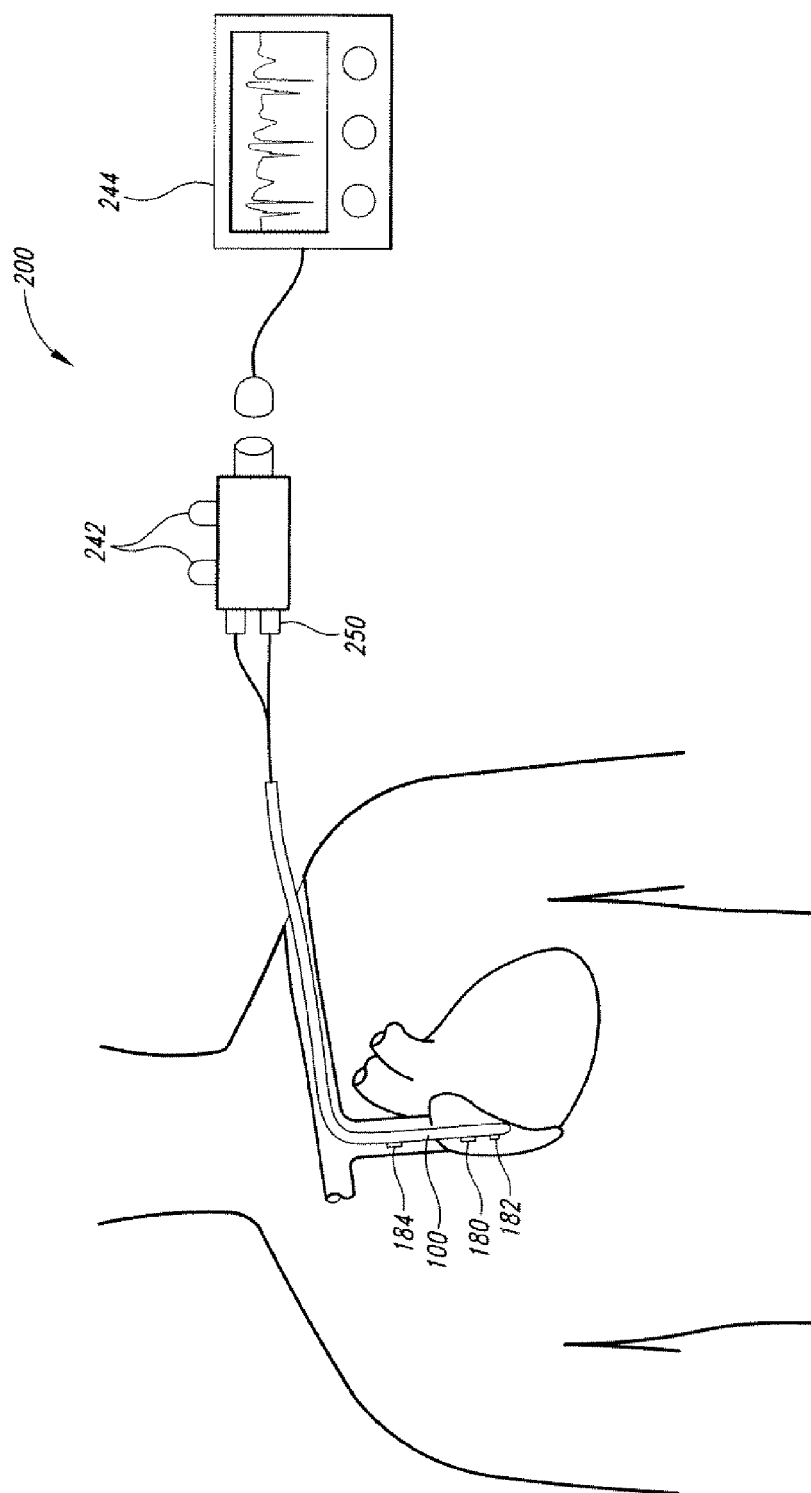


Fig. 7

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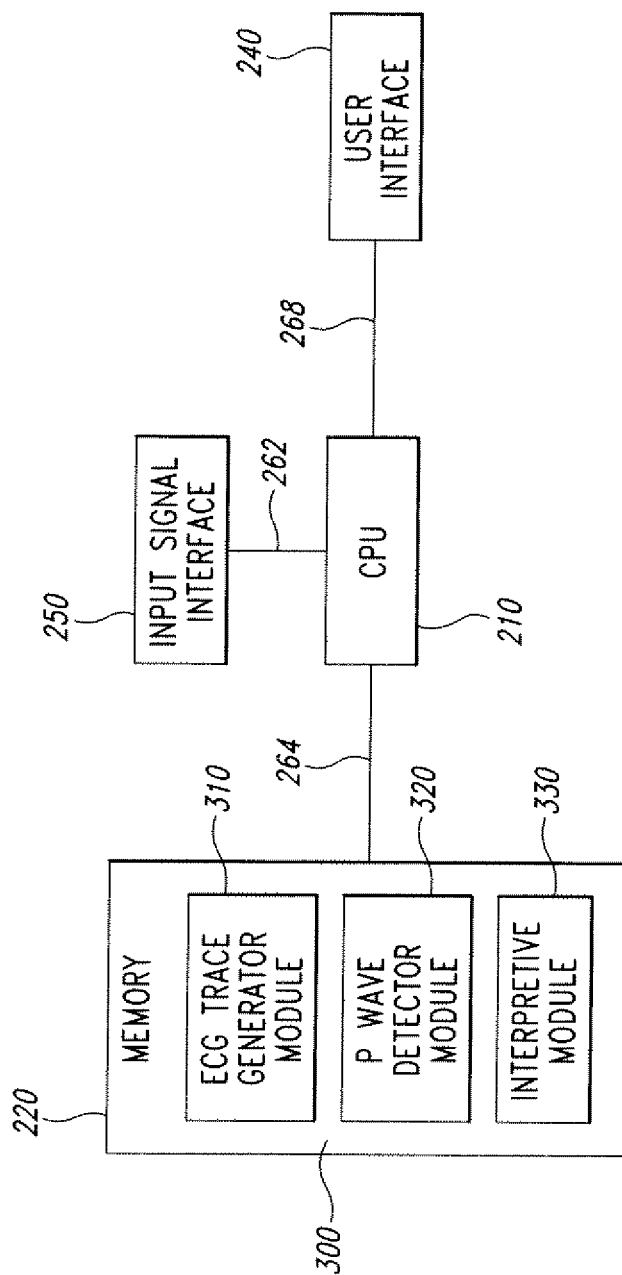


Fig. 8

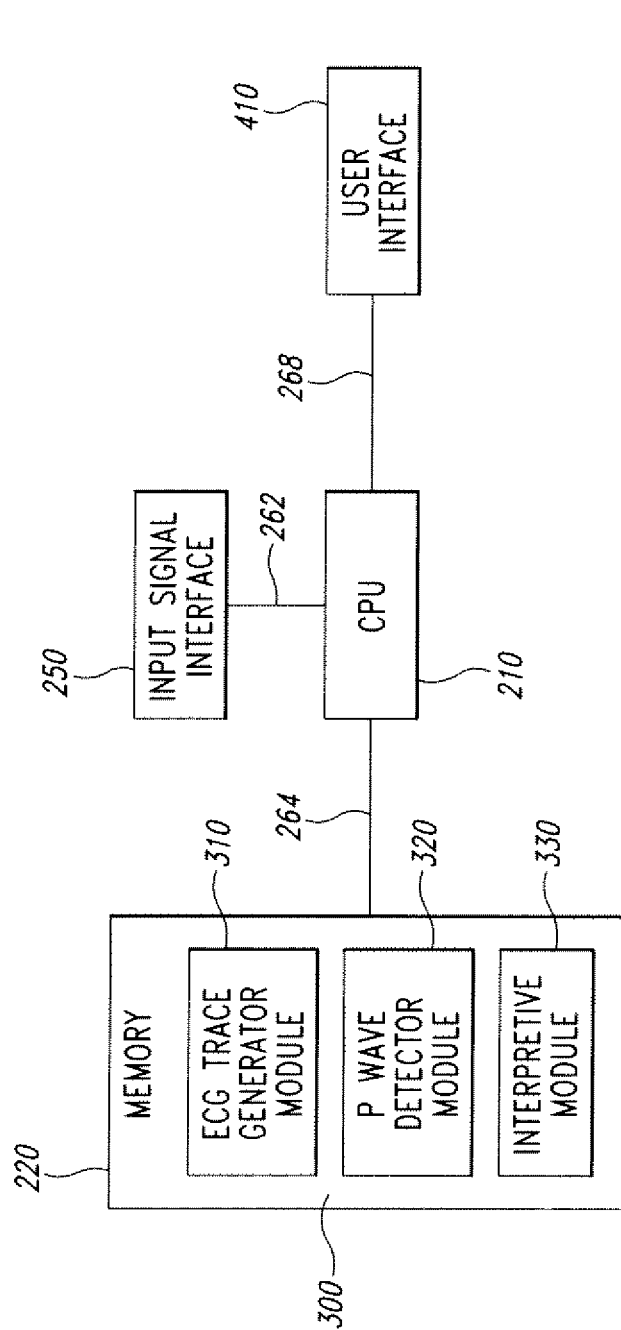
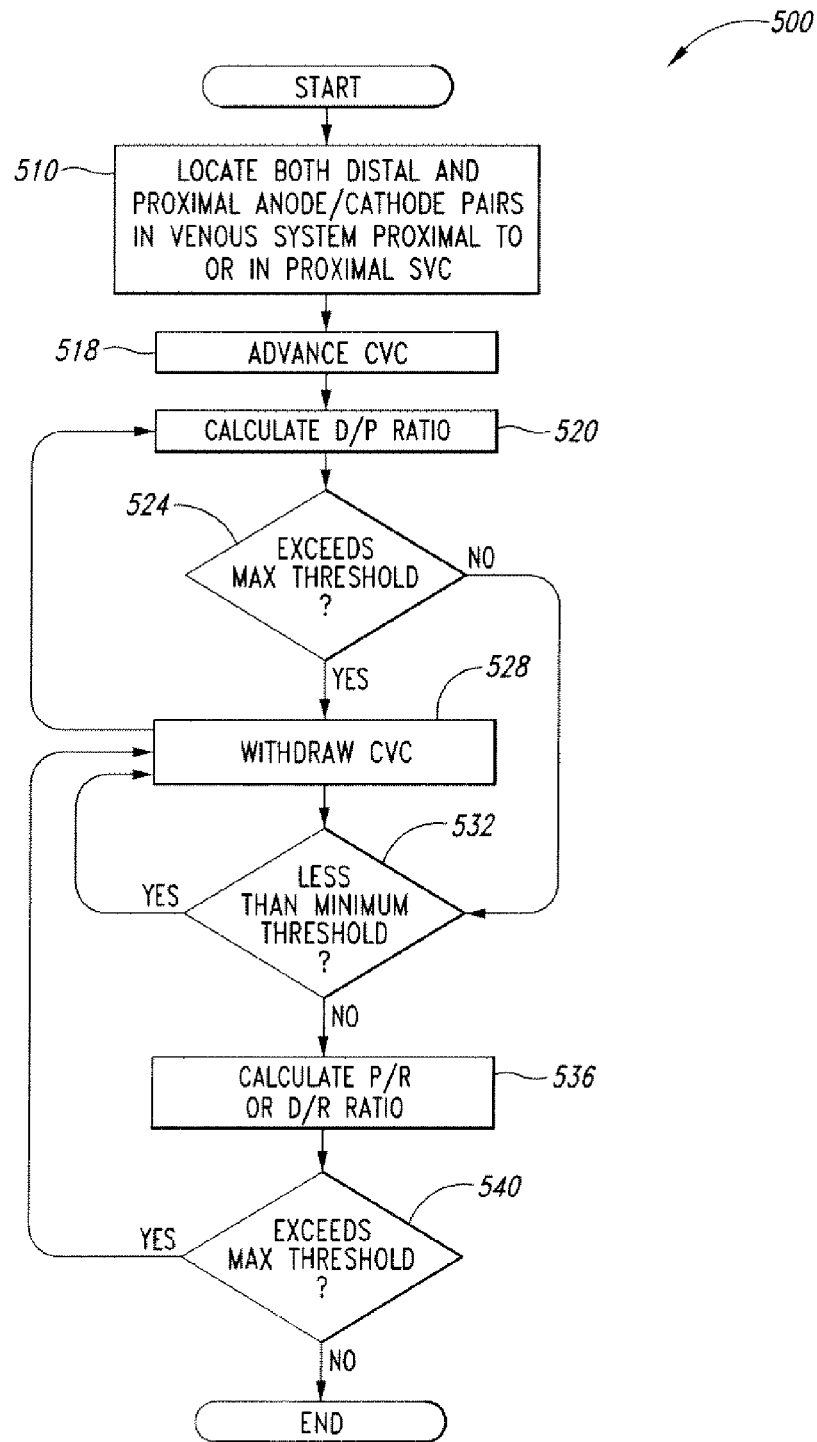
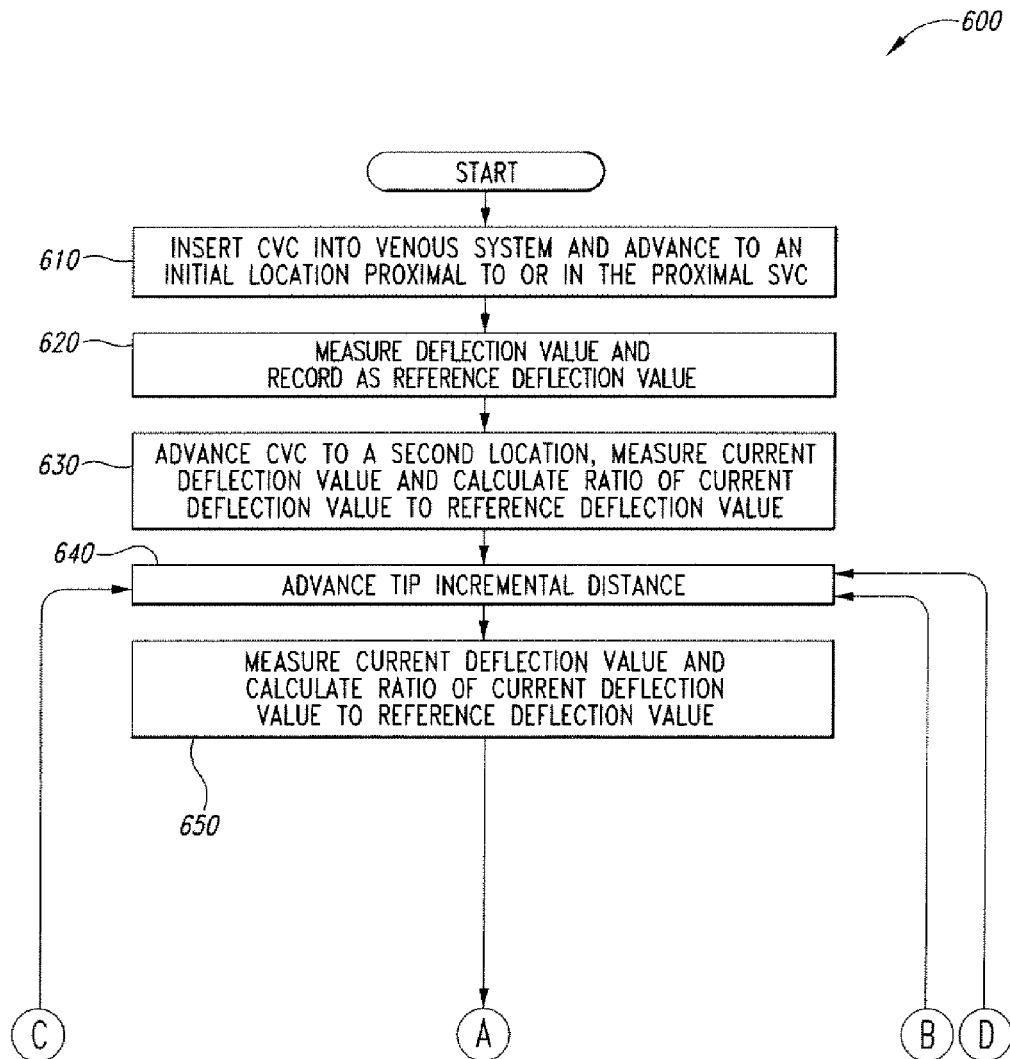
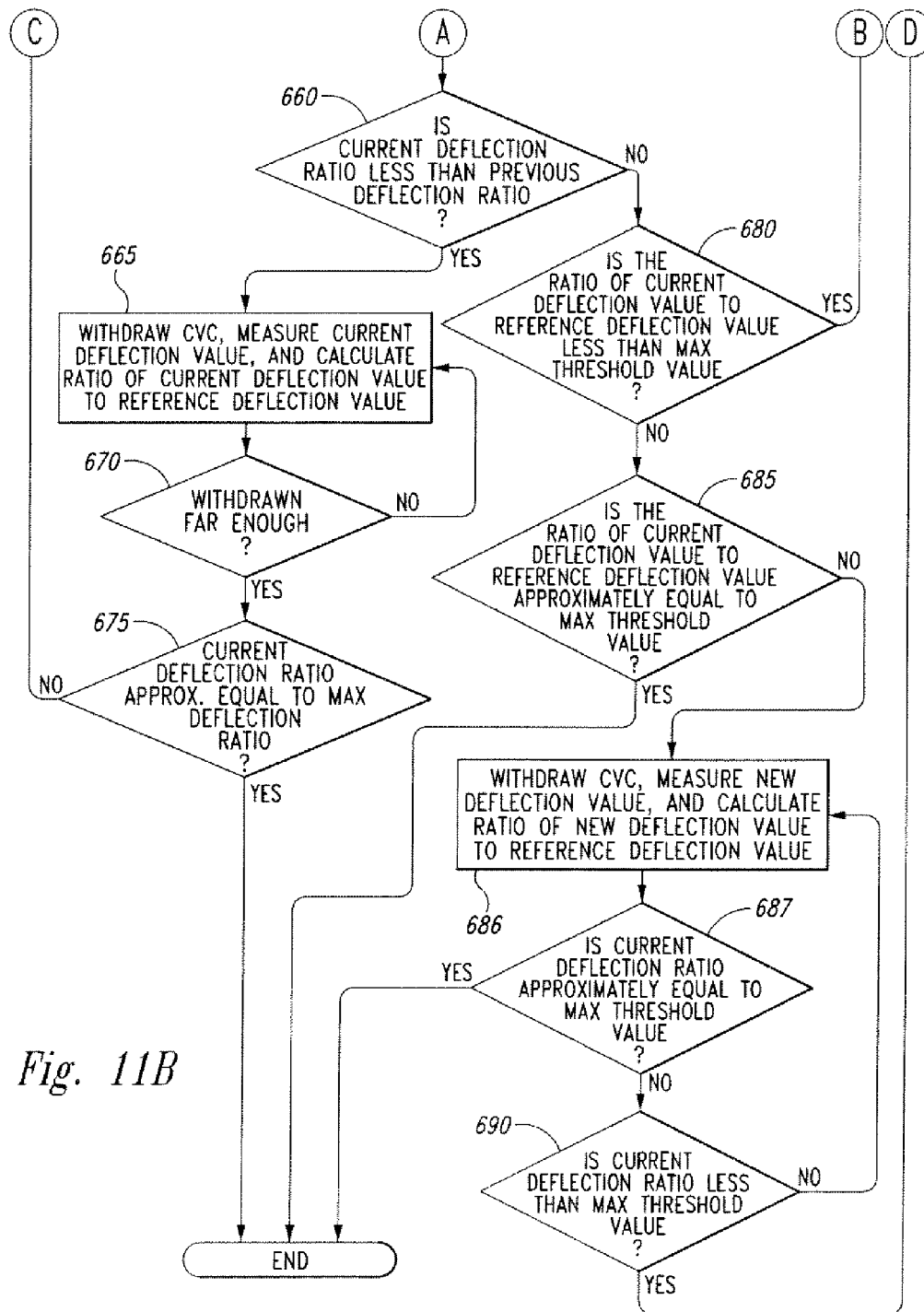


Fig. 9

*Fig. 10*



*Fig. 11A*



## METHOD OF LOCATING THE TIP OF A CENTRAL VENOUS CATHETER

### CROSS REFERENCE TO RELATED APPLICATION(S)

This application is a division of U.S. patent application Ser. No. 13/737,806, filed Jan. 9, 2013, now U.S. Pat. No. 8,774,907, which is a division of U.S. patent application Ser. No. 12/427,244, filed Apr. 21, 2009, now U.S. Pat. No. 8,388,546, which is: 1) a continuation of International Application No. PCT/US2009/033116, filed Feb. 4, 2009, claiming priority under 35 U.S.C. §119(e) to U.S. Provisional Application No. 61/026,372, filed Feb. 5, 2008; and 2) a continuation-in-part of U.S. patent application Ser. No. 11/552,094, filed Oct. 23, 2006, now U.S. Pat. No. 7,794,407. Each of the aforementioned applications is incorporated by reference in its entirety into this application.

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention is directed generally to devices for and methods of locating a catheter inside a body and more particularly to devices for and methods of locating the tip of a central venous catheter inside the superior vena cava, right atrium, and/or right ventricle using information obtained from an electrocardiogram.

#### 2. Description of the Related Art

Central venous catheters ("CVC") include any catheter designed to utilize the central veins (e.g., subclavian and superior vena cava) or right sided cardiac chambers for the delivery and/or withdrawal of blood, blood products, therapeutic agents, and/or diagnostic agents. CVCs also include catheters inserted into the central veins or right sided cardiac chambers for the acquisition of hemodynamic data. Standard central venous catheters for intravenous access, dialysis catheters, percutaneously introduced central catheters ("PICC" lines), and right heart ("Swan-Ganz™") catheters are examples of CVCs.

The standard of care for placing a CVC (other than right heart catheters which generally terminate in the pulmonary artery) dictates that the tip of the CVC lie just above and not inside the right atrium. In fact, in 1989, the Food and Drug Administration issued a warning citing an increased risk of perforation of the right atrium, clot formation, and arrhythmias among other potential complications resulting from the tip of the CVC being placed inside the right atrium.

While CVCs have been used for many years, determining the position of the tip of the CVC has always been problematic. Currently, a chest x-ray is used to determine the position of the tip of the CVC. Because CVC may be a radiopaque and/or include radiopaque materials, the CVC is visible on an x-ray. However, this method has several drawbacks. For example, obtaining a chest x-ray is labor intensive and expensive. In recent years, CVCs, which were traditionally placed in a hospital in-patient setting, are being placed in an outpatient setting more frequently. In an outpatient setting, obtaining a chest x-ray to determine the position of the tip of the CVC can be very cumbersome and may not be obtained in a timely manner. Therefore, using a chest x-ray to determine the position of the tip of the CVC may introduce a considerable delay, prolonging the procedure. Generally, the operator will leave the patient to perform other duties while the x-ray is processed. If the tip is improperly placed, the operator must return to the patient's bedside to reposition the CVC. To

reposition the CVC, the operator must open the sterile dressing, cut the sutures, re-suture, and redress the wound, all of which potentially expose the patient to discomfort and infection.

Recently, navigational systems principally used to guide peripherally placed lines have become available. Based upon the detection of magnetic fields between a stylet tip and a detector, these systems assume (and depend upon) a relationship between surface landmarks and anatomic locations. Unfortunately, these systems cannot be used to determine the location of the tip of a CVC with sufficient accuracy because the relationship between surface landmarks and anatomic locations is highly variable from one patient to another.

In addition to the need to know where the tip is during initial placement, the CVC may migrate or otherwise move after the initial placement and require re-positioning. Therefore, the operator must monitor or periodically reevaluate the location of the tip.

An electrocardiogram ("ECG") measures electrical potential changes occurring in the heart. Referring to FIGS. 1A-1C, the ECG measurements may be visualized or displayed as an ECG trace, which includes ECG waveforms. As is appreciated by those of ordinary skill in the art, ECG waveforms are divided into portions that include a QRS complex portion and a P wave portion in addition to other wave portions. The QRS complex corresponds to the depolarization of the ventricular muscle. The P wave portion of the ECG waveforms represents atrial muscle depolarization: the first half is attributable to the right atrium and the second half to the left atrium. Under normal circumstances, atrial muscle depolarization is initiated by a release of an excitatory signal from the sino-atrial ("SA") node, a specialized strip of tissue located at the juncture of the superior vena cava ("SVC") and right atrium.

As is appreciated by those of ordinary skill in the art, an ECG may be obtained using different electrode configurations. For example, a standard configuration referred to as "Lead II" may be used. In a bipolar Lead II configuration, one of the electrodes (the cathode) is attached to the left leg and the other electrode (the anode) is attached to the right shoulder. As is appreciated by those of ordinary skill in the art, using a different configuration could change the polarity and/or the shape of the P wave. Other standard bipolar configurations include a bipolar Lead I configuration where the cathode is attached to the left shoulder and the anode is attached to the right shoulder and a bipolar Lead III configuration where the cathode is attached to the left leg and the anode is attached to the right shoulder.

The waveforms depicted in FIGS. 1A-1C and 2B were obtained using the anode of a standardized bipolar ECG Lead II configuration attached to the right shoulder and the tip of the CVC as the cathode. While technically this configuration is not a standard Lead II configuration, the trace produced by the electrodes 114A and 114B may be displayed on a standard ECG monitor using the monitor's circuitry to display the trace as a bipolar Lead II trace.

Techniques of using ECG waveforms to locate the tip of a CVC have been available since the 1940's. Some of these prior art devices construct an intravascular ECG trace by placing an electrode near the tip of the CVC and using that electrode to measure the voltage near the tip of the CVC relative to a surface electrode(s) and/or a second electrode spaced from the first.

These techniques have shown that both the magnitude and shape of the P wave change depending upon the positioning or location of the electrode attached to the tip of the CVC. Referring to FIGS. 1A and 1B, two exemplary ECG traces are provided for illustrative purposes.

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FIG. 1A is an ECG trace made when the electrode attached to the tip of the CVC is in the proximal SVC. This tip location corresponds to position "1" depicted in FIG. 2A. The portion of the ECG trace corresponding to an exemplary P wave produced when the electrode attached to the tip is located in position "1" is labeled "P1."

FIG. 1B is an ECG trace made when the electrode attached to the tip of the CVC is approaching the SA node and stops at a location adjacent to the SA node. These tip locations correspond to moving the tip from a position "2" to position "3" depicted in FIG. 2A. The portion of the ECG trace corresponding to an exemplary P wave produced when the electrode attached to the tip is approaching the SA node is labeled "P2" and the portion of the ECG trace corresponding to an exemplary P wave produced when the electrode attached to the tip is located adjacent to the SA node is labeled "P3."

Normally as the electrode attached to the tip of the CVC moves from the proximal SVC (position "1") toward the SA node (position "3"), the maximum value of the absolute value of the voltage of the P wave increases dramatically. When the electrode attached to the tip of the CVC is adjacent to the SA node (position "3"), the voltage of the P wave (please see "P3" of FIG. 1B) reaches a maximum value that is more than twice the value experienced in the proximal SVC and may be as large as eight times the voltage in the proximal SVC. When this occurs, the tip of the CVC is considered to have entered into the right atrium. Because the magnitude of the P wave more than doubles when the electrode attached to the tip of the CVC is adjacent to the SA node, this information may be used to place the tip of the CVC within a few centimeters (e.g., about 1 cm to about 2 cm) proximal to the SA node. Additionally, as the electrode attached to the tip of the CVC moves from the proximal SVC toward the right atrium, the shape of the P wave changes from a "u" shape (FIG. 1A) to a spike-like shape (FIG. 1B).

Referring to FIG. 2B, another exemplary illustration of the P wave portion of the ECG trace produced when the electrode attached to the tip of the CVC is located at positions 1-5 depicted in FIG. 2A is provided. The P wave portions of the ECG traces of FIG. 2B are labeled with the letter "P" and occur between the vertical dashed lines. Each of the exemplary traces is numbered to correspond to positions "1" through "5." Therefore, the ECG trace "1" was produced when the electrode attached to the tip was located in the proximal SVC. The trace "2" was produced when the electrode attached to the tip was in position "2" (distal SVC). The trace "3" was produced when the electrode attached to the tip was adjacent to the SA node.

As the electrode attached to the tip of the CVC is advanced further into the right atrium, the polarity of the P wave "P" changes from predominantly negative near the top of the right atrium (position "3") to isoelectric (i.e., half has a positive polarity and half has a negative polarity) near the middle of the right atrium (position "4") to almost entirely positive at the bottom of the right atrium (position "5"). These changes in the P wave "P" are illustrated in traces "3" through "5."

FIG. 1C is an ECG trace made when the electrode attached to the tip of the CVC is in the right ventricle. The portion of the ECG trace corresponding to an exemplary P wave produced when the electrode attached to the tip is labeled "P6." When the electrode attached to the tip of the CVC is advanced into the right ventricle, the maximum magnitude of the absolute value of the P wave "P6" approximates the maximum magnitude of the absolute value of the P wave "P1" when the electrode attached to the tip of the CVC was inside the proximal SVC above the SA node (i.e., located at position "1").

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However, the polarity of the first half of P wave "P6," which corresponds to the right atrium, is opposite.

The first technique developed for viewing the ECG waveform during the insertion of a CVC used a column of saline disposed within a hollow tube or lumen longitudinally traversing the CVC. The column of saline provides a conductive medium. Saline was inserted into the lumen by a saline filled syringe with a metal needle. The needle of the syringe remained within the entrance to the lumen or port in contact with the column of saline after the lumen was filled. One end of a double-sided alligator clip was attached to the needle and the other end was attached to an ECG lead, which in turn was attached to an ECG monitor. By using the saline solution filled CVC as a unipolar electrode and a second virtual electrode generated by ECG software from three surface electrodes, an intravascular ECG was obtained. The operator would adjust the position of the tip of the CVC based on the magnitude and shape of the P wave displayed by the ECG monitor.

Subsequently, this technique was modified by substituting an Arrow-Johans adapter for the metal needle. The Arrow-Johans adapter is a standard tubing connector with an embedded conductive ECG eyelet. The Arrow-Johans adapter may be placed in line with any conventional CVC. In a closed system, the tubing and CVC may be filled with saline, i.e., a conductive medium, and the CVC used as a unipolar electrode in conjunction with surface electrodes and a standard ECG monitor. The ECG eyelet is placed in contact with the saline in the lumen of the CVC. One end of the ECG lead is attached to the ECG eyelet and the other end to the ECG monitor for displaying the intravascular ECG waveforms. Because the system must be closed to prevent the saline from leaking out, this system works best after the guide wire used to thread the CVC forward has been withdrawn, i.e., after placement has been completed. Therefore, although the catheter may be withdrawn after initial placement, it may not be advanced into proper position.

B. Braun introduced its Certofix catheter to be used in conjunction with its CERTODYN adapter. In this system, a patch lead with two ends has an alligator clip connected to one end. The alligator clip is clipped to the CVC guide wire. The other end of the patch lead includes a connector that is plugged into the CERTODYN adapter. The ECG may be obtained during placement and the catheter may be advanced or withdrawn as desired. However, the CERTODYN adapter has many moving parts and is not sterile, making the procedure cumbersome to perform and the operative field more congested. Additionally, the sterile field may become contaminated by the non-sterile equipment.

The Alphacard, manufactured by B. Braun, merges the Arrow-Johans adapter and the CERTODYN adapter. The Alphacard consists of a saline filled syringe (used to flush the CVC with saline) and a connector to the CERTODYN. The Alphacard is used to obtain a 'snapshot' of the ECG trace from the saline column. If an atrial spike is seen in the ECG trace, the CVC is withdrawn.

With respect to all of these prior art methods of using an ECG trace to place the tip of the CVC, some degree of expertise is required to interpret the P waves measured because the user must advance the guide wire slowly and watch for changes in the P wave. If the catheter is inserted too far too quickly and the changes to the P wave go unnoticed (i.e., the operator fails to notice the increase or spike in the voltage experienced when the electrode attached to the tip is in the right atrium), the operator may mistakenly believe the tip is in the SVC when, in fact, the tip is in the right ventricle. If this occurs, advancing the tip may injure the patient.

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U.S. Pat. Nos. 5,078,678 and 5,121,750 both issued to Katims teach a method of using the P wave portion of an ECG trace to guide placement of the tip of the CVC. The CVC includes two empty lumens into which a transmission line is fed or an electrolyte is added. Each of the lumens has a distal exit aperture located near the tip of the CVC. The two exit apertures are spaced from one another. In this manner, two spaced apart electrodes or a single anode/cathode pair are constructed near the tip of the CVC. The voltage or potential of one of the electrodes relative to the other varies depending upon the placement of the electrodes. The voltage of the electrodes is conducted to a catheter monitoring system. The catheter monitoring system detects increases and decreases in the voltage of the P wave. The voltage increases as the electrodes approach the SA node and decrease as the electrodes move away from the SA node. Based on whether the voltage is increasing or decreasing, the operator is instructed by messages on a screen to advance or withdraw the CVC.

While Katims teaches a method of locating the tip of a CVC relative to the SA node, Katims relies on advancing or withdrawing the CVC and observing the changes of the P wave. Katims does not disclose a method of determining the location of the tip of the CVC based on a single stationary position. Unless the entire insertion procedure is monitored carefully, the method cannot determine the position of the tip of the CVC. Further, the Katims method may be unsuitable for determining the location of a previously positioned stationary tip.

Other devices such as Bard's Zucker, Myler, Gorlin, and CVP/Pacing Lumen Electrode Catheters are designed primarily to pace. These devices include a pair of electrodes at their tip that are permanently installed and designed to contact the endocardial lining. These devices include a lumen, which may be used to deliver and/or withdraw medications or fluids as well as for pressure monitoring. These leads are not designed for tip location and do not include multi-lumen capability.

A method of obtaining an intravascular ECG for the purposes of placing a temporary pacing wire was described in U.S. Pat. No. 5,666,958 issued to Rothenberg et al. Rothenberg et al. discloses a bipolar pacing wire having a distal electrode. The distal electrode serves as a unipolar electrode when the pacing wire is inserted into the chambers of the heart. The pacing wire is connected to a bedside monitor through a specialized connector for the purposes of displaying the ECG waveforms detected by the distal electrode.

Given the volume of CVCs placed yearly and the increasing demand particularly for PICC lines (devices that permit the delivery of intravenous therapeutic agents in the outpatient setting, avoiding the need for hospitalization) a great need exists for methods and devices related to locating the tip of a CVC. Particularly, devices and methods are needed that are capable of determining the location of the tip before the operator leaves the bedside of the patient. Further, a method of determining the location (SVC, right atrium, or right ventricle) of the tip from a single data point rather than from a series of data points collected as the catheter is moved may be advantageous. Such a system may be helpful during initial placement and/or repositioning. A need also exists for a device for or a method of interpreting the ECG waveforms that does not require specialized expertise. Methods and devices that avoid the need for hospital and x-ray facilities are also desirable. A need also exists for devices and methods related to determining the position of the tip of the CVC that

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are less expensive, expose patients to fewer risks, and/or are less cumbersome than the x-ray method currently in use.

#### BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

FIG. 1A is an exemplary ECG trace obtained from an electrode placed inside the proximal SVC.

FIG. 1B is an exemplary ECG trace obtained from an electrode approaching the sino-atrial node and stopping adjacent thereto.

FIG. 1C is an exemplary ECG trace obtained from an electrode placed inside the right ventricle.

FIG. 2A is an illustration of a partial cross-section of the heart providing five exemplary tip locations 1, 2, 3, 4, and 5.

FIG. 2B is a series of exemplary P wave traces 1, 2, 3, 4, and 5 obtained from an electrode placed in each of the exemplary tip locations 1, 2, 3, 4, and 5 depicted in FIG. 2A, respectively.

FIG. 3A is a signal analysis system configured to determine the position of the tip of a CVC using a single pair of electrodes.

FIG. 3B is an embodiment of a CVC including three pairs of electrodes.

FIG. 4 is a block diagram illustrating a method of using a single pair of electrodes to locate the tip of the CVC within the SVC.

FIG. 5 is a block diagram illustrating a method of using a single pair of electrodes to determine the tip of the CVC is located within the right ventricle.

FIG. 6 is a block diagram illustrating a method of using a single pair of electrodes to determine the location of the tip of the CVC within the right atrium.

FIG. 7 is an embodiment of a signal analysis system for use with the CVC of FIG. 3B.

FIG. 8 is a block diagram illustrating the components of the signal analysis system of FIG. 7.

FIG. 9 is block diagram illustrating the components of a monitor of the signal analysis system of FIG. 3A.

FIG. 10 is a block diagram illustrating a method of using at least two pairs of electrodes to locate the tip of the CVC relative to the SVC, right atrium, and right ventricle.

FIGS. 11A-11B are a block diagram illustrating an alternate method of using a single pair of electrodes to locate the tip of the CVC relative to the SA node.

#### DETAILED DESCRIPTION OF THE INVENTION

##### Central Venous Catheter 100

Aspects of the present invention are directed toward a device for locating the tip of a central venous catheter ("CVC") and a method of determining the location of the tip of a CVC. The embodiments depicted in FIGS. 3A and 3B, include a CVC 100 constructed using any manner known in the art from a flexible nonconductive material, such as polyurethane or other suitable polymer material. It may also be desirable to use a radiopaque material to construct the CVC 100. As is appreciated by those of ordinary skill in the art, the material used to construct the CVC 100 may include materials and/or coatings that provide improved anti-thrombotic or anti-bacterial properties. The CVC 100 has a body 130 configured to be received within a central vein. The body 130 may include a distal end 110 having a tapered tip 112 and a proximal end 120 spaced longitudinally along the body 130 from the distal end 110.

Referring to FIG. 3A, the body 130 may include one or more lumens 132 that traverse the length of the body and may

have one or more openings **134** at or spaced from the tip **112** and an open end portion **122** configured to permit access into the lumen **132**. When the tip **112** of the CVC **100** is received within a central vein, the open end portion **122** may remain outside the central vein allowing materials (e.g., saline, medications, etc.) to be inserted into the lumen **132** while the tip **112** is inside the central vein or another anatomical structure. The opening **134** permits the passage of materials between the lumen **132** and the environment outside the CVC **100**. If one or more materials are inserted into the lumen **132** via the open end portion **122**, those materials may exit the lumen **132** via the opening **134**. If materials enter the lumen **132** via the opening **134**, those materials may exit the lumen **132** via the open end portion **122**.

The open end portion **122** is configured to be coupled to a connector **124** through which materials may be introduced into or exit from the open end portion **122** of the lumen **132**. The connector **124** may include any suitable connector known in the art including a Tuohy-Borst adapter, stop cock, and the like. In the embodiment depicted in FIG. 3A, the connector **124** is a Tuohy-Borst adapter, which includes a side port **125** through which materials (e.g., saline) may be introduced into the open end portion **122** of the lumen **132**. The side port **125** may be used to flush the lumen **132** with normal saline or another material. The connector **124** is configured to maintain materials within the lumen **132** and to prevent those materials from leaking out of the CVC **100** through the open end portion **122**.

The lumens **132** may be used as conduits for the passage of materials such as medications and/or other fluids to and from the environment outside the CVC **100**. For example, the lumen **132** may be used to aspirate blood into the CVC **100** and/or provide a conduit through which pressure data may be collected and used to construct pressure waveforms. The environment outside the CVC **100** may include the inside of the SVC, right atrium, and/or right ventricle. The CVC **100** is provided for illustrative purposes and those of ordinary skill in the art appreciate that alternate embodiments of CVC **100** including embodiments with additional lumens, a flow directed balloon tip, thermistors, thermolulution ports, pacing wire ports, embedded pacing electrodes, and the like are within the scope of the present invention.

#### Deflection Value

The deflection of an ECG trace, (i.e., its vertical height relative to the baseline) may be used to compare two or more P waves. Because a P wave constitutes a voltage change over time, the deflection of the P wave is not constant. In particular embodiments, the P wave is represented by an array or series of discrete numerical values.

The deflection value may be calculated in several ways. For example, the maximum or peak deflection may be used. Alternatively, the deflection value may be calculated as the difference between the maximum deflection and the minimum deflection. The deflection value may also be calculated as the sum of the absolute value of the maximum and minimum deflections. If the P wave has two peaks, which may occur when the tip **112** is located within the right atrium and the P wave is biphasic (see position 4 of FIGS. 2A and 2B), the deflection value may be calculated by totaling the absolute value of the two peaks. When this method is used, the deflection value of the P wave measured at positions 3-5 may all be approximately equal. Further, if discrete data is being used, the deflection value may also be calculated as a total of the discrete deflection quantities. If continuous data is being used, the deflection value may also be calculated as the inte-

gral under the P wave. Further, the deflection value may also be calculated as the average P wave deflection. Because the polarity of portions of the P wave change depending upon the location of the tip **112**, it may be beneficial to use the absolute value of the deflection of the P wave to calculate the deflection value.

For the purposes of this application, the term “deflection value” will be used hereafter to describe the metric used to compare two or more P waves, which depending upon the implementation details may be detected by one or more pairs of electrodes. It is appreciated by those of ordinary skill in the art that the deflection value may be determined in numerous ways including those listed above and others not listed and the invention is not limited by the method and manner of determining the deflection value of the P wave.

In the embodiments discussed below, unless otherwise indicated, the deflection value is calculated as the sum of the absolute value of the maximum and minimum deflections when the maximum and minimum deflections have opposite polarities. The deflection value is calculated as the larger of the absolute value of the maximum and minimum deflections when the maximum and minimum deflections have the same polarity. In other words, the vertical height of the P wave is used.

#### Embodiments Using a Single Pair of Electrodes

Referring to FIG. 3A, an embodiment of a system **121** using a single pair of electrodes **114** to determine the position of the tip **112** of the CVC **100** will be described. An electrolytic material or solution, such as saline, may be disposed inside the lumen **132**. The electrolytic material inside the lumen **132** forms a continuous conductor or column of electrolytic material that may be used to conduct an electrical signal from the opening **134** in the tip **112**, and up the continuous column. In other words, the opening **134** exposes the electrolytic material inside the lumen **132** to electrical activity occurring in the environment outside the tip **112**. A first electrode **114A** of the pair of electrodes **114** is placed in electrical communication with the continuous column inside the lumen **132**. The first electrode **114A** may be coupled by a wire **123** to a monitor **127**.

A second or surface electrode **114B** is placed in contact with the skin of a patient. By way of a non-limiting example, the surface electrode **114B** may be affixed to the skin of the patient's chest using any method known in the art. The surface electrode **114B** is coupled to the monitor **127** by a wire **129**. The voltage at or near the opening **134** in the tip **112** may be measured using the pair of electrodes **114**.

The voltages detected by the pair of electrodes **114** may be used to create an ECG trace of the electrical activity observed at or near the tip **112** of the CVC **100**. Because the voltage across each of the pair of electrodes **114** may vary with time, the voltage across wires **123** and **129** may constitute a time-varying signal that can be analyzed using standard signal processing methods well known in the art. In a typical patient, the maximum voltage across the pair of electrodes **114** may range from about 0.2 mV to about 3 mV. The signal detected by the pair of electrodes **114** may be amplified and/or filtered to improve the signal quality.

In the embodiment depicted in FIG. 3A, the first electrode **114A** is coupled to the connector **124**. Alternatively, the first electrode **114A** may be located inside at least a portion of the lumen **132**. By way of another example, the first electrode **114A** is coupled to the side port **125** through which the electrolytic material (e.g., saline) may be introduced into the open end portion **122** of the lumen **132**. As is apparent to those

of ordinary skill in the art, the first electrode **114A** may be located anywhere that would place it in electrical continuity or communication with the electrolytic material (e.g., saline) exiting the tip **112** via the opening **134** or otherwise communicating electrically with the environment outside the opening **134** of the tip **112**. By way of another example, the first electrode **114A** may be incorporated into a guide wire (not shown), stylet, and the like that extends from, or near the tip **112** up the body **130** of the CVC **100** and is electrically coupled by the wire **123** to the monitor **127**. The monitor **127** is described in detail below.

#### Method of Using a Single Electrode Pair to Determine the Position of the Tip of the CVC

Referring to FIG. 4, a method **140** of determining the location of the tip **112** using the pair of electrodes **114** will now be described. In block **141**, the CVC **100** is inserted into the SVC. The CVC **100** may gain venous access to the SVC by any method known in the art including inserting the CVC **100** in a standard sterile fashion through the subclavian, one of the jugular veins, or a peripheral vein and directing the tip **112** of the CVC **100** through that vein toward the proximal SVC.

Next, in block **142**, a reference deflection value is recorded in a storage location. The reference deflection value is the deflection value obtained from the pair of electrodes **114** when the tip **112** is located in the venous system proximal to or in the proximal SVC.

Then, in block **143**, the tip **112** is advanced. As the tip **112** is advanced, a ratio of the deflection value of the currently observed P wave to the reference deflection value is calculated. Inside the SVC, as the tip **112** approaches the mid SVC, the deflection value of the P wave may increase by two to four times the reference deflection value. Further, as the tip **112** approaches the distal SVC, the deflection value of the P wave may increase by four to six times the reference deflection value. In the distal SVC near the SA node, the deflection value of the P wave may increase by six to eight times the reference deflection value.

In decision block **144**, whether the ratio is less than or equal to a first predefined threshold value is determined. The first predefined threshold value should be large enough to ensure the tip **112** has left the proximal SVC and entered the mid SVC. Further, the first predefined threshold value should be small enough to prevent placement of the tip **112** in the distal SVC. Thus, the first predefined threshold value may be within a range of about 1.6 to about 3.9. By way of a non-limiting example, the first predefined threshold value may be about 2.0. If the ratio is less than or equal to the first predefined threshold value, in block **143**, the tip **112** may be advanced and the ratio recalculated. Ratio values less than or equal to the first predefined threshold value indicate the tip **112** is in the proximal or mid SVC and has not yet reached either the distal SVC, caval-atrial junction adjacent to the SA node or the upper right atrium.

If decision block **144** determines the ratio is not less than or equal to the first predefined threshold value, the method **140** advances to decision block **145**. In decision block **145**, whether the ratio is less than or equal to a second predefined threshold value is determined. The second predefined threshold value should be large enough to ensure the tip **112** is in the distal SVC and small enough to avoid entry of the tip **112** into the right atrium. By way of a non-limiting example, the second predefined threshold value may within a range of about 4.0 to about 8.0. By way of a non-limiting example, the second predefined threshold value may be about 8.0. In other

words, the block **144** determines whether the ratio is between the first and second threshold values or within a range defined between the first and second threshold values (e.g., about 2.0 to about 8.0). Nevertheless, ratio values within the range defined between the first and second threshold values may indicate the tip **112** is approaching or has reached the SA node, or the tip is located within the right atrium. In other words, any ratio value above the second predefined threshold value may indicate the tip **112** is located in the distal SVC or the upper atrium. If the ratio is within the range defined between the first and second threshold values, the decision in decision block **145** is "YES" and the method **140** ends.

If the ratio is greater than the second threshold value, the decision in decision block **145** is "NO," and the method **140** advances to block **147**. When the ratio is greater than the second threshold value, the tip **112** is in or near the right atrium and in block **147**, the user or operator is advised to withdraw the tip **112**. By way of a non-limiting example, the user or operator may be advised to withdraw the tip **112** about 0.5 cm to about 1 cm. Then, in block **147**, advancement of the tip **112** is terminated and the tip **112** withdrawn. By way of a non-limiting example, the user or operator may withdraw the tip **112** about 0.5 cm to about 1 cm. In block **147**, as the tip **112** is withdrawn, the ratio of the deflection value of the currently observed P wave to the reference deflection value is recalculated.

Then, the method **140** returns to decision block **144**.

In particular embodiments, if at any time during the performance of method **140**, the ratio is equal to the second predefined threshold value, the tip **112** is maintained in its current position without additional advancement or withdrawal and the method **140** ends. When the method **140** ends, the ratio is between the first and second threshold values and the tip **112** is located in the mid SVC or distal SVC.

The following table, Table 1, summarizes the relationship between the location of the tip **112** of the CVC **100** and the ratio of the deflection value of the currently observed P wave to the reference deflection value:

TABLE 1

	Location of the tip 112			
	Proximal SVC	Mid SVC	Distal SVC	Very Distal SVC or Right Atrium
Ratio: ratio of the deflection value of the currently observed P wave to the reference deflection value	≤1.5	1.6-4.0	4.1-5.5	>5.5-8.0

While Table 1 provides exemplary ranges and/or threshold values for use as a general guideline, those of ordinary skill in the art appreciate that these values may benefit from adjustment as additional anatomic or electrophysiologic data is acquired and such modified values are within the scope of the present invention.

As is apparent to those of ordinary skill, the pair of electrodes **114** may be used to detect the instantaneous location of the tip **112**. Therefore, if the tip **112** migrates into the atrium, this movement may be detected immediately by calculating a ratio of the deflection value of the currently observed P wave to the recorded reference deflection value and comparing the ratio to the first and second threshold values. This calculation may be performed periodically or at random intervals. If the

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tip 112 migrates into the atrium, a medical professional may be alerted via a signal, such as an alarm, and the like, to reposition the tip 112.

Referring to FIG. 5, a method 450 may be used to determine the tip 112 is located within the ventricle. In first block 452, the tip 112 is located in the atrium. Then, in block 454, a reference atrium deflection value is recorded. The reference atrium deflection value is the deflection value obtained from the pair of electrodes 114 when the tip 112 is located in the atrium. Then, in block 456, a ratio of the deflection value of the current P wave detected by the pair of electrodes 114 to the reference atrium deflection value is determined. In decision block 457, whether the ratio is greater than a third predefined threshold value is determined. The third predefined threshold value may be about 0.5. If the decision is "YES," the ratio is greater than the third predefined threshold value, and in block 458, the tip 112 is determined to be in the right atrium. Then, the method 450 ends. If the decision in decision block 457 is "NO," the ratio is less than or equal to the third predefined threshold value, and in block 459, the tip 112 is determined to be in the right ventricle. Then, the method 450 ends.

Within at least a portion of the range defined between the first and second threshold values (e.g., about 2.0 to about 8.0), the P wave voltage measured using prior art techniques, such as those disclosed by U.S. Pat. Nos. 5,078,678 and 5,121,750 (both issued to Katims), has generally not yet reached its maximum value. Therefore, the present method indicates the tip 112 should be withdrawn before those techniques would signal withdrawal. For example, typically the P wave voltage within the proximal SVC is about 0.2 to about 0.3 mV. Near the SA node, the P wave voltage may increase about 8 fold (e.g., about 1.6 mV to about 2.4 mV. In other words, the ratio is about 8 near the SA node, which is the location of the maximum P wave voltage used in the prior art. However, prior art techniques advise to advance the tip until it can be clearly seen that the maximum P voltage has been reached. Therefore, the prior art techniques allow the tip 112 to advance further into the right atrium than the present technique before identifying the advancement should be halted and the tip withdrawn back into the SVC. Because the present technique halts the advancement of the tip 112 earlier (e.g., when the P wave voltage increases above the second predefined threshold value of about 8.0, which corresponds to about 1.6 mV to about 2.4 mV) than prior art techniques, the present teachings may avoid many of the risks associated with advancing the tip into the right atrium.

Further, the prior art teaches using a threshold percentage decrease to determine the tip 112 is in the correct location. However, using a threshold percentage decrease may be ineffective at locating the tip 112 within the SVC because the percentage decrease may vary from patient to patient. In other words, depending upon the anatomical structures of the patient, the tip 112 may have to be withdrawn until the percentage decreases differing amounts. On the other hand, if the tip 112 is withdrawn until the ratio is between about 2.0 and about 8.0 (e.g., the current P wave voltage is about 0.4 mV to about 2.4 mV), the tip will be located in the mid SVC or in some cases, the distal SVC. Therefore, the present technique more accurately positions the tip 112 than prior art techniques.

In addition to halting the advancement of the tip 112 when the ratio of the deflection value of the currently observed P wave to the reference deflection value has exceeded either of the first and second predefined threshold values, advancement of the tip 112 could also be halted when the deflection

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value of the currently observed P wave is approximately equivalent to the voltage (or deflection value) of the QRS complex.

As discussed above, when observed using a standard bipolar Lead II trace, the P wave voltage is almost entirely negative at the top of the right atrium (see trace 3 of FIG. 2B), biphasic in the mid right atrium (see trace 4 of FIG. 2B), and positive at the bottom of the right atrium (see trace 5 of FIG. 2B). A positive/total deflection ratio may be calculated and used to determine when advancement of the tip 112 should be halted. The positive/total deflection ratio is a ratio of the greatest positive deflection value (of an initial positive or upwardly deflecting portion that precedes a downwardly deflecting portion) to the total deflection value of the currently observed P wave. When the positive/total deflection ratio is greater than a predetermined fraction (e.g., one quarter, one eighth, etc.) advancement of the tip 112 should be halted. For example, the traces 3-5 illustrated in FIG. 2B each have an initial upwardly deflecting portion. However, in both cases, the greatest positive deflection value of the initial upwardly deflecting portion of the P wave is clearly greater than one quarter of the total deflection value of the currently observed P wave. As explained above, in these traces, the tip 112 is located in the right atrium. Thus, if the greatest positive deflection value is greater than the predetermined fraction of the total deflection value of the currently observed P wave, the tip 112 is in the right atrium and should be withdrawn.

#### Alternate Method of Using a Single Electrode Pair to Determine the Position of the Tip of the CVC

FIGS. 11A and 11B provide a block diagram of an alternate method 600 of advancing and locating the tip 112 of the CVC 100. A physical cathode-anode electrode pair is used in a standard bipolar lead setup. A bipolar lead setup means two physical leads are used (rather than one virtual lead and one physical lead, which are referred to as a unipolar lead setup).

For illustrative purposes, the method 600 is described using the first electrode 114A (see FIG. 3A) functions as a cathode at the tip 112 and the second electrode 114B (see FIG. 3A) functions as an anode attached to the patient's skin near his/her right shoulder. The continuous conductor or column inside the lumen 132, which is in electrical communication with both the first electrode 114A and the electrical activity occurring in the environment outside the tip 112 functions as a "wandering electrode," which is the positive cathode. The second electrode 114B serves as the negative anode electrode. While technically this configuration is not a standard Lead II configuration, the trace produced by the electrodes 114A and 114B may be displayed on a standard ECG monitor using the monitor's circuitry to display the trace as a bipolar Lead II trace. Thus, an ECG trace is generated for the wandering electrode relative to the electrode "RA," which is displayed as a Lead II trace. However, as is apparent to those of ordinary skill in the art, through application of ordinary skill in the art to the present teachings other ECG Lead traces could be used and are within the scope of the present disclosure.

As is apparent to those of ordinary skill in the art, in a standard unipolar lead setup, three surface electrodes (not shown) are attached to a patient's skin: an electrode "RA" is attached to the patient's right arm (or shoulder), an electrode "LA" is attached to the patient's left arm (or shoulder), and an electrode "LL" is attached to the patient's left leg. A virtual electrode may be created using ECG software, which calculates the virtual electrode as the electrical center of an Einthoven's triangle created by the electrodes "RA," "LA," and "LL" used in the Lead I, Lead II, and Lead III configu-



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rations. The continuous conductor or column inside the lumen 132, which is in electrical communication with both the first electrode 114A and the electrical activity occurring in the environment outside the tip 112 functions as a "wandering electrode." The wandering electrode is the positive cathode, and the virtual electrode is the negative anode electrode. Thus, an ECG trace is derived for the wandering electrode relative to the virtual electrode. In addition to Leads I, II, and III (of the bipolar configurations), some ECG monitors display unipolar lead configurations, e.g., aVR, aVL, aVF derived from a composite of the electrodes "RA," "LA" and "LL," or a chest electrode, variably called a "V," "MCL," or "Chest" lead (hereafter referred to as the "V" lead). Some ECG monitors display this ECG trace as a unipolar "V" lead trace and some users particularly like to use the unipolar "V" lead trace to guide the tip 112 of the CVC 100. However, most users use the bipolar Lead II trace generated for the wandering electrode relative to the electrode "RA" (i.e., the ECG Lead II configuration discussed above). As is apparent to those of ordinary skill in the art, with respect to the method 600, any number of bipolar or unipolar lead configurations may be used with acceptable results. Further, either the unipolar "V" lead trace or the bipolar Lead II trace (among others) may be used to perform the method 140.

In method 600, the deflection values measured include only the negative polarity or downwardly extending portion of the P-wave. The upwardly extending positive polarity portion is not included in the measurement of the deflection values. Thus, the deflection value is calculated as the absolute value of the minimum deflection.

In first block 610, the CVC 100 is introduced into the venous system and advanced to an initial location estimated to place the tip 112 of the CVC 100 at or proximal to the proximal SVC. In next block 620, a deflection value of the P wave observed at the initial location is measured and stored as a reference deflection value.

Then, in block 630, the CVC 100 is advanced from the initial location to a second location. By way of a non-limiting example, the CVC 100 may be advanced from the initial location about 0.5 cm to about 1.0 cm in block 630. At the second location, a new deflection value is measured using of the P wave observed at the second location. A deflection ratio of the new deflection value to the reference deflection value is then calculated. As the method 600 is performed, a maximum deflection ratio observed is stored. Thus, in block 630, the maximum deflection value observed is equal to the deflection ratio observed at the second location.

In block 640, the CVC 100 is advanced from the second location by an incremental distance. By way of a non-limiting example, the incremental distance may be within a range of about 0.5 cm to about 1.0 cm. However, a smaller sized incremental distance may be used and is within the scope of the present teachings.

After the CVC 100 has been advanced by the incremental distance, in block 650, a current deflection value of the P wave observed at the new location is measured and a current deflection ratio of the current deflection value to the reference deflection value is calculated. If the current deflection ratio is greater than the maximum deflection ratio, the maximum deflection ratio is set equal to the current deflection ratio. Before the CVC 100 was advanced, the CVC was located at a previous location. The deflection value measured at the previous location is a previous deflection value and the deflection ratio of the previous deflection value to the reference deflection value is a previous deflection ratio.

Then, in decision block 660, the current deflection ratio is compared to the previous deflection ratio. The decision in

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decision block 660 is "YES" when the current deflection ratio is less than the previous deflection ratio. Otherwise, the decision in decision block 660 is "NO."

When the decision in decision block 660 is "YES," in block 665, the CVC 100 is withdrawn from the current location to a new location. By way of a non-limiting example, in block 665, the CVC 100 may be withdrawn about 0.5 cm to about 1.0 cm. Then, a new deflection value of the P wave observed at the new location is measured and a new deflection ratio of the new deflection value to the reference deflection value is calculated. If the new deflection ratio is greater than the maximum deflection ratio, the maximum deflection ratio is set equal to the new deflection ratio. At this point, the location of the CVC 100 before withdrawal is a previous location and the deflection ratio calculated at the previous location is a previous deflection ratio. The location of the CVC 100 after withdrawal is a current location and the deflection ratio calculated at the current location is a current deflection ratio. By way of a non-limiting example, the CVC 100 may be withdrawn about 1 cm. Then, the method 600 advances to decision block 670.

In decision block 670 whether the CVC 100 has been withdrawn far enough is determined. In decision block 670, a positive/total deflection ratio of the greatest positive deflection value (of an initial positive or upwardly deflecting portion which precedes a downwardly deflecting portion) to the total deflection value of the currently observed P wave is calculated. The decision in decision block 670 is "YES" when the positive/total deflection ratio is less than a predetermined fraction (e.g., one quarter, one eighth, etc.). Otherwise, the decision in decision block 670 is "NO."

Alternatively, in decision block 670, a negative/total deflection ratio of the smallest negative deflection value (of a negative polarity or downwardly deflecting portion of the currently observed P wave which follows an upwardly deflecting positive polarity portion of the currently observed P wave) to the total deflection value of the currently observed P wave is calculated. The decision in decision block 670 is "YES" when the negative/total deflection ratio is greater than or equal to a predetermined fraction (e.g., three quarters, seven eighths, etc.). Otherwise, the decision in decision block 670 is "NO."

When the decision in decision block 670 is "YES," the method 600 advances to decision block 675. When the decision in decision block 670 is "NO," the method 600 returns to block 665.

In decision block 675, the current deflection ratio is compared to the maximum deflection ratio observed. The decision in decision block 675 is "YES" when the current deflection ratio is approximately equal to the maximum deflection ratio observed. By way of a non-limiting example, the current deflection ratio may be considered approximately equal to the maximum deflection ratio observed when the absolute value of the difference between the current deflection ratio and the maximum deflection ratio observed is less than 0.2. If the current deflection ratio is not approximately equal to the maximum deflection ratio observed, the decision in decision block 675 is "NO."

When the decision in decision block 675 is "YES," the method 600 ends. When the decision in decision block 675 is "NO," the method 600 returns to block 640.

When the decision in decision block 660 is "NO," the current deflection ratio (calculated after the CVC 100 was advanced by the current incremental distance) is greater than or equal to the previous deflection ratio (calculated after the CVC 100 was advanced by the previous incremental dis-

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tance). When the decision in decision block **660** is "NO," the method **600** advances to decision block **680**.

The decision in decision block **680** is "YES," when the current deflection ratio is less than a maximum threshold value. Otherwise, decision in decision block **680** is "NO." By way of a non-limiting example, the maximum threshold value may be about 8.0.

When the decision in decision block **680** is "YES," the current deflection ratio is less than the maximum threshold value (e.g., 8.0) and greater than the previous deflection ratio. When this is the case, the method **600** returns to block **640**.

When the decision in decision block **680** is "NO," the current deflection ratio is greater than or equal to the maximum threshold value (e.g., 8.0), and the method **600** advances to decision block **685** to determine whether the current deflection ratio is approximately equal to the maximum threshold value.

When the current deflection ratio is approximately equal to the maximum threshold value, the decision in decision block **685** is "YES." Otherwise, decision in decision block **685** is "NO." The current deflection ratio may be considered approximately equal to the maximum threshold value when the absolute value of the difference between the current deflection ratio and the maximum threshold value is less than 0.2.

When the decision in decision block **685** is "YES," the method **600** ends. When the decision in decision block **685** is "NO," the current deflection value is neither less than nor equal to the maximum threshold value. When this occurs, the method **600** progresses to block **686** whereat the CVC **100** is withdrawn from the current location to a new location. Then, a new deflection value of the P wave observed at the new location is measured and a new deflection ratio of the new deflection value to the reference deflection value is calculated. The location of the CVC **100** after withdrawal is a current location and the deflection ratio calculated at the current location is a current deflection ratio. By way of a non-limiting example, the CVC **100** may be withdrawn about 1 cm. Then, the method **600** advances to decision block **687**.

In decision block **687**, the current deflection ratio is compared to the maximum threshold value. The decision in decision block **670** is "YES" when the current deflection ratio is approximately equal to the maximum threshold value. By way of a non-limiting example, the current deflection ratio may be considered approximately equal to the maximum threshold value when the absolute value of the difference between the current deflection ratio and the previous deflection ratio is less than 0.2. When the current deflection ratio is not approximately equal to the maximum threshold value, the decision in decision block **687** is "NO."

When the decision in decision block **687** is "YES," the method **600** ends. When the decision in decision block **670** is "NO," the method **600** advances to decision block **690**. Decision block **690** determines whether the CVC **100** was withdrawn too far in block **686**. The decision in decision block **690** is "YES" when the current deflection ratio is less than maximum threshold value. When this occurs, continuing to withdraw the CVC **100** will simply reduce the current deflection value. Thus, to make the current deflection ratio approximately equal to the maximum threshold value, the CVC **100** must be advanced.

The decision in decision block **690** is "NO" when the current deflection ratio is greater than the maximum threshold value. Thus, to make the current deflection ratio approximately equal to the maximum threshold value, the CVC **100** must be withdrawn. When the decision in decision block **690** is "NO," the method **600** returns to block **686**.

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If at anytime during the performance of the method **600**, the current deflection ratio is approximately equal to the previously observed maximum deflection ratio, advancement and withdrawal of the CVC **100** may be halted and performance of the method **600** terminated. Similarly, if at anytime during the performance of the method **600**, the current deflection ratio is approximately equal to the maximum threshold value, advancement and withdrawal of the CVC **100** is halted and performance of the method **600** terminated.

#### Method of Using a Single Electrode Pair to Determine the Location of the Tip of the CVC within the Right Atrium

As discussed above, the P wave voltage is almost entirely negative at the top of the right atrium (see trace 3 of FIG. 2B), biphasic in the mid right atrium (see trace 4 of FIG. 2B), and positive at the bottom of the right atrium (see trace 5 of FIG. 2B). Referring to FIG. 6, a method **190** uses these characteristics of the P wave voltage to determine the location of the tip **112** of the CVC **100** within the atrium. As is apparent to those of ordinary skill in the art, with respect to the method **190**, either the unipolar "V" lead trace or the bipolar Lead II trace may be used.

In block **191**, any method known in the art or described herein is used to determine the tip **112** is located in the atrium. For example, the tip **112** is in the atrium when the ratio of the deflection value of the currently observed P wave to the reference deflection value is greater than a value that may vary from person to person but is within a range of about 4.0 to about 8.0. Alternatively, the tip **112** may be determined to be in the atrium when the P wave voltage has exceeded a predetermined amount (e.g., about 0.8 mV to about 2.4 mV). Further, the tip **112** may be determined to be in the atrium when the positive/total deflection ratio (i.e., a ratio of the greatest positive deflection value of the initial upwardly deflecting portion of the currently observed P wave, which precedes a downwardly deflecting portion, to the total deflection value) is greater than the predetermined fraction (e.g., one quarter, one eighth, etc.). By way of another example, the tip **112** may be determined to be in the atrium when the voltage (or deflection value) of the currently observed P wave is approximately equivalent to or greater than the voltage (or deflection value) of the QRS complex.

After it is determined the tip **112** is in the right atrium, in block **192**, a positive/negative deflection ratio is calculated. The positive/negative deflection ratio is a ratio of the greatest positive deflection value to the smallest negative deflection value. As discussed above, the absolute value of the deflection values may be used. Thus, the positive/negative deflection ratio may be calculated as a ratio of the deflection value having the largest absolute value within the portion of the P wave that has a positive polarity to the deflection value having the largest absolute value within the portion of the P wave having a negative polarity. If the P wave is entirely negative, the positive/negative ratio is zero (and the tip **112** is in the upper atrium). On the other hand, if the largest positive deflection value and the smallest negative deflection value are equal, the positive/negative deflection ratio is equal to one. In subsequent blocks **193-197**, the positive/negative deflection ratio is used to determine whether the tip **112** is located in the upper, mid, or lower atrium.

In decision block **193**, whether the positive/negative deflection ratio is less than a first predetermined threshold value is determined. The first predetermined threshold value may be about 0.80. If decision block **193** determines the ratio is less than the first predetermined threshold value, in block

194, the method 190 determines the tip 112 is in the upper atrium and the method 190 ends.

If decision block 193 determines the ratio is not less than the first predetermined threshold value, the method 190 advances to decision block 195. In decision block 195, whether the positive/negative deflection ratio is greater than a second predetermined threshold value is determined. The second predetermined threshold value may be about 1.20. If decision block 195 determines the ratio is greater than the second predetermined threshold value, in block 196, the method 190 determines the tip 112 is in the lower atrium and the method 190 ends.

If decision block 195 determines the ratio is not greater than the second predetermined threshold value, in block 197, the method 190 determines the tip 112 is in the mid atrium and the method 190 ends. In other words, if the positive/negative deflection ratio is between the first and second predetermined threshold values, the tip 112 is in the mid atrium. Further, if the positive/negative deflection ratio is equal to the first predetermined threshold value or the second predetermined threshold value, the tip 112 is in the mid atrium.

The following table summarizes the relationship between the location of the tip 112 of the CVC 100 and the positive/negative deflection ratio:

TABLE 2

	Location of the tip 112		
	Upper Atrium	Mid Atrium	Lower Atrium
Positive/Negative Deflection Ratio: ratio of the greatest positive deflection value to the smallest negative deflection value	<0.80	0.80-1.20	>1.20

While Table 2 provides exemplary ranges and/or threshold values for use as a general guideline, those of ordinary skill in the art appreciate that these values may benefit from adjustment as additional anatomic or electrophysiologic data is acquired and such modified values are within the scope of the present invention.

#### Embodiments Using Two or More Pairs of Electrodes

In the embodiment depicted in FIG. 3B, the CVC 100 includes four longitudinally spaced apart electrodes 150, 152, 154, and 156. Each electrode 150, 152, 154, and 156 is in electrical communication with a wire 160, 162, 164, and 166, respectively. In particular embodiments, the electrodes 150, 152, 154, and 156 are constructed from the distal end of each of the wires 160, 162, 164, and 166. In another embodiment, the electrodes 150, 152, 154, and 156 are attached to the ends of the wires 160, 162, 164, and 166 by any method known in the art for attaching an electrode to a wire, including soldering. The wires 160, 162, 164, and 166 are electrically isolated from one another. The wires 160, 162, 164, and 166 may be insulated from the environment outside the body 130 by the body 130.

The electrodes 150, 152, 154, and 156 and the wires 160, 162, 164, and 166 may be constructed from any suitable materials known in the art such as stainless steel or platinum. Alternatively, a column of conductive material such as an electrolytic material (e.g., saline) may be used to construct one or more of the electrodes 150, 152, 154, and 156 and/or the wires 160, 162, 164, and 166. The electrodes 150, 152,

154, and 156 may be about 6 mm to about 12 mm long, about 6 mm to about 12 mm wide, and about 1 mm to about 4 mm thick. The wires 160, 162, 164, and 166 may be constructed using any electrical lead wire suitable for obtaining an ECG trace.

Optionally, the invention may include two longitudinally spaced apart electrodes 157 and 158. Each of the electrodes 157 and 158 may be electrical communication with a wire 167 and 168, respectively. The electrodes 157 and 158 and wires 167 and 168 may be constructed in a manner substantially similar to that used to construct the electrodes 150, 152, 154, and 156 and the wires 160, 162, 164, and 166, respectively. In particular embodiments, the electrode 157 and 158 are positioned proximal to the electrodes 150, 152, 154, and 156.

Electrodes 150, 152, 154, and 156 may form two anode/cathode pairs. For example, electrodes 150 and 152 may form a first or proximal anode/cathode pair 180 and electrodes 154 and 156 may form a second or distal anode/cathode pair 182. Optional electrodes 157 and 158 may form an optional third or reference anode/cathode pair 184. A pair of electrodes forming an anode/cathode pair may be attached to a pair of insulated wires housed within a single cable. In particular embodiments, a pair of bipolar lead wires are used. In this manner, the four electrodes of the proximal and distal anode/cathode pairs 180 and 182 may be attached to two lead wires. A third bipolar lead wire may be included for use with the reference anode/cathode pair 184. Alternatively, the proximal and distal anode/cathode pairs 180 and 182 may be attached to four insulated wires housed within a single cable such as a dual bipolar lead wire.

The wires 160, 162, 164, and 166 and electrodes 150, 152, 154, and 156 may be permanently embedded into the body 130 of the CVC 100 or removably inserted into one or more channels or lumens 132 formed in the CVC 100 for potential future removal and/or replacement. The wires 167 and 168 and electrodes 157 and 158 may be incorporated into the CVC 100 in any manner described with respect to wires 160, 162, 164, and 166 and electrodes 150, 152, 154, and 156, respectively.

The electrodes 150, 152, 154, and 156 are in electrical communication with the environment outside the CVC 100. In particular embodiments, a portion of each of the electrodes 150, 152, 154, and 156 are exposed to the environment outside the CVC 100 by apertures 170, 172, 174, and 176 formed in the body 130 adjacent to the electrodes 150, 152, 154, and 156, respectively. In embodiments including optional electrodes 157 and 158, a portion of each of the electrodes 157 and 158 may be exposed to the environment outside the CVC 100 by apertures 177 and 178 formed in the body 130 adjacent to the electrodes 157 and 158, respectively. The apertures 177 and 178 may be constructed in any manner suitable for constructing apertures 170, 172, 174, and 176. The apertures 170, 172, 174, and 176 may be formed in the body 130 by any method known in the art and the invention is not limited by the method used to construct the apertures 170, 172, 174, and 176. While the electrodes 150, 152, 154, and 156 depicted in the drawings extend outwardly from the body 130 through the apertures 170, 172, 174, and 176, it is understood by those of ordinary skill in the art, that electrodes 150, 152, 154, and 156 may reside at the bottom of the apertures 170, 172, 174, and 176 which may provide a passageway for fluids in the outside environment to the electrodes 150, 152, 154, and 156. Alternatively, the portion of the electrodes 150, 152, 154, and 156 in electrical communication with the environment outside the CVC 100 may be flush with the outside surface of the CVC 100.

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The electrode **156** may be located at or spaced from the tip **112**. In particular embodiments, the electrode **156** is less than about 5 mm from the tip **112**. The spacing between an anode and cathode of the anode/cathode pairs **180** and **182** may be about 1 mm to about 4 mm. In particular embodiments, the spacing between an anode and cathode of the anode/cathode pairs **180** and **182** is about 3 mm.

In particular embodiments, the distance between the electrodes **154** and **152** is less than the height of the right atrium. In an adult, the height of the right atrium may be approximately equal to or greater than about 4 cm. In one exemplary embodiment, the distance between the electrode **154** and **152** may be about 3 cm. In embodiments including optional electrodes **157** and **158**, the distance between the electrodes **150** and **158** may be about 10 cm to about 18 cm.

Those of ordinary skill in the art appreciate that the size and spacing of the electrodes provided herein may require modification for use with patients that are larger or smaller than a typical adult and such embodiments are within the scope of the present invention. For example, smaller electrodes with a closer spacing may be required for use with a pediatric patient.

Referring to FIG. 7, the CVC **100** may gain venous access to the SVC by any method known in the art including inserting the CVC **100** in a standard sterile fashion through the subclavian, one of the jugular veins, or a peripheral vein and directing the tip **112** of the CVC **100** through that vein to the SVC.

Each of the anode/cathode pairs **180** and **182** may be used to generate an ECG trace. In this manner, the ECG waveforms detected by the proximal pair **180** may be compared to the ECG waveform detected by the distal pair **182**. In particular embodiments, the P wave portion of each trace is compared to determine the position of the tip **112** of the CVC **100** within the SVC, right atrium, and right ventricle.

In embodiments including the reference anode/cathode pair **184**, the reference anode/cathode pair **184** may be used to generate an ECG trace. Referring to FIG. 7, because the reference anode/cathode pairs **184** may be located substantially proximally from the proximal and distal anode/cathode pairs **180** and **182**, the reference anode/cathode pair **184** may remain in the venous system proximal to or in the proximal SVC after the proximal and distal anode/cathode pairs **180** and **182** have entered the heart. In particular embodiments, the spacing between the anode/cathode pair **184** and the proximal pair **180** is large enough to insure the reference anode/cathode pair **184** remains proximal to or inside the proximal SVC when the distal anode/cathode pair **182** is inside the right ventricle. In this manner, the reference anode/cathode pair **184** may be used to detect the ECG waveform within venous system proximal to or in the proximal SVC while the catheter is being placed.

The ECG waveforms detected by the proximal anode/cathode pair **180** and/or distal anode/cathode pair **182** may be compared to the ECG waveform detected by the reference anode/cathode pair **184**. In particular embodiments, the P wave portion of the ECG trace detected by the proximal anode/cathode pair **180** and/or distal anode/cathode pair **182** is compared to P wave portion of the ECG trace detected by the reference anode/cathode pair **184** to determine whether the tip **112** of the CVC **100** is located within the SVC, right atrium, or right ventricle.

#### Methods of Determining the Location of the Tip of the CVC Using Two or More Electrode Pairs

As is apparent to those of ordinary skill in the art, the methods **140**, **450**, **190**, and **600** described above may be

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performed using the CVC **100** with two or three pairs of electrodes. With respect to each of the methods **140**, **450**, **190**, and **600**, the electrode **156** of the distal anode/cathode pair **182** may be substituted for the first electrode **114A** (see FIG. 3A) and the electrode **154** of the distal anode/cathode pair **182** may be substituted for the second electrode **114B** (see FIG. 3A). By way of another non-limiting example, any one of the electrodes **156**, **154**, or **152** may be used as the cathode and any one of the electrodes **154**, **152**, or **150** proximal to the one used as the cathode may be used as the anode. Alternatively, with respect to each of the methods **140**, **450**, **190**, and **600**, one or both of the distal anode/cathode pair **182** may be substituted for the first electrode **114A** (see FIG. 3A) and one or both of the proximal anode/cathode pair **180** may be substituted for the second electrode **114B** (see FIG. 3A). However, as is appreciated by those of ordinary skill in the art, it may be desirable to use the distal most electrode as the cathode.

Referring to FIG. 10, an alternate method **500** of determining the location of the tip **112** of the CVC **100** using two or three pairs of electrodes will now be described. With respect to method **500**, unless otherwise indicated, the deflection value is calculated as the sum of the absolute value of the maximum and minimum deflections when the maximum and minimum deflections have opposite polarities. The deflection value is calculated as the larger of the absolute value of the maximum deflection and the absolute value of the minimum deflection when the maximum and minimum deflections have the same polarity.

In first block **510**, both the distal anode/cathode pair **182** and the proximal anode/cathode pair **180** are located in the venous system proximal to or in the proximal SVC. A D/P ratio of the deflection value of the distal anode/cathode pair **182** to the deflection value of the proximal anode/cathode pair **180** may be calculated and used to verify the locations of the distal anode/cathode pair **182** and the proximal anode/cathode pair **180** within the venous system proximal to or in the proximal SVC. When both of the anode/cathode pairs **180** and **182** are within the venous system proximal to or in the proximal SVC, the deflection value of the P wave detected by each of them is substantially identical and the D/P ratio of their P wave deflection values equals approximately one. Optionally, the deflection value of one or both of the P waves may be stored or otherwise recorded. For example, the deflection value of the P wave detected by the distal anode/cathode pair **182** or the proximal anode/cathode pair **180** may be stored as a reference deflection value.

In next block **518**, the user advances the CVC **100**. By way of a non-limiting example, the user may advance the CVC **100** about 0.5 cm to about 1.0 cm. Then, in block **520**, the D/P ratio of the deflection value of the distal anode/cathode pair **182** to the deflection value of the proximal anode/cathode pair **180** is calculated. Optionally, the deflection value of one or both of the P waves may be stored or otherwise recorded. Then, the method **500** advances to decision block **524**.

The user or operator may wish to continue advancing the CVC **100** until the SA node is detected. When an anode/cathode pair **180** or **182** is approximately 4 cm proximal to the SA node and therefore, by inference, approximately 4 cm proximal to the entrance of the right atrium (or "caval-atrial junction," which is the location of the SA node), the deflection value of the P wave detected by that anode/cathode pair may increase.

When the distal anode/cathode pair **182** enters the right atrium and the proximal anode/cathode pair **180** is still in the venous system proximal to or in the proximal SVC, the deflection value of the P wave detected by the distal anode/

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cathode pair **182** may be at least four times the deflection value of the P wave detected by the proximal anode/cathode pair **180**. Therefore, when the D/P ratio of the P wave deflection values of the distal anode/cathode pair **182** to the proximal anode/cathode pair **180** is greater than or equal to about 4.0 to about 8.0, the user or operator should withdraw the CVC **100**. By way of a non-limiting example, the user may withdraw the CVC **100** about 0.5 cm to about 1.0 cm.

In decision block **524**, a predetermined maximum threshold value "TR1" may be used to determine whether the user or operator should withdraw the CVC **100**. If the D/P ratio exceeds the maximum threshold value "TR1," the decision in decision block **524** is "YES," and in block **528**, the CVC **100** is withdrawn. In particular embodiments, the maximum threshold value "TR1" may range from approximately 4.0 to approximately 8.0. By way of a non-limiting example, the maximum threshold value "TR1" may be about 8.0. If the D/P ratio does not exceed the maximum threshold value "TR1," the decision in decision block **524** is "NO," and the method **500** advances to decision block **532**.

When the distal anode/cathode pair **182** enters the right ventricle, the proximal anode/cathode pair **180** may be in the right atrium. Because the deflection value of the P wave experienced in the right ventricle is approximately equal to the deflection value of the P wave experienced in the proximal SVC, the D/P ratio of the P wave deflection values of the distal anode/cathode pair **182** to the proximal anode/cathode pair **180** (which is now in the upper atrium) is less than or equal to about one half. Therefore, when the D/P ratio is less than about one half, the user or operator should withdraw the CVC **100**.

In decision block **532**, a predetermined minimum threshold value "TMIN" may be used to determine whether the user or operator should withdraw the CVC **100**. If the D/P ratio is less than the predetermined minimum threshold value "TMIN," the decision in decision block **532** is "YES," and in block **528**, the CVC **100** is withdrawn. In particular embodiments, the predetermined minimum threshold value "TMIN" may be approximately one half.

If the D/P ratio is not less than the minimum threshold value "TMIN," the decision in decision block **532** is "NO," and the distal anode/cathode pair **182** and the proximal anode/cathode pair **180** may both be in the right atrium at the same time. When this occurs, the deflection value of the P waves detected by each would be very similar if not identical making their D/P ratio approximately equal to one. Therefore, in block **536**, a P/R ratio or D/R ratio (described below) may be calculated to determine the location of the tip **112** of the CVC **100**.

The P/R ratio may include the ratio of the deflection value of the P wave detected by the proximal anode/cathode pair **180** to the stored reference deflection value of the P wave detected in the proximal SVC. In particular embodiments, the P/R ratio may include the ratio of the deflection value of the P wave detected by the proximal anode/cathode pair **180** to a reference deflection value of the P wave detected by the reference anode/cathode pair **184**. In embodiments that include a reference anode/cathode pair **184**, the reference anode/cathode pair **184** may be used to detect the P wave in the proximal SVC. Because the proximal anode/cathode pair **180** is inside the right atrium, the deflection value of its P wave is greater than or equal to about four times to about eight times the deflection value of the P wave observed in the proximal SVC. When the P/R ratio is equal to or greater than a threshold value "TR2" within a range of about 4.0 to about

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8.0, the user or operator should withdraw the CVC **100**. By way of a non-limiting example, the threshold value "TR2" may be about 4.0. By way of a non-limiting example, the threshold value "TR2" may be equal to the predetermined maximum threshold value "TR1." Alternatively, the threshold value "TR2" could be set equal the largest D/R ratio observed thus far.

After the P/R ratio is calculated, in decision block **540**, the threshold value "TR2" may be used to determine whether the user or operator should withdraw the CVC **100**. If the P/R ratio exceeds the threshold value "TR2," the decision in decision block **540** is "YES," and in block **528**, the CVC **100** is withdrawn. Otherwise, if the P/R ratio does not exceed the threshold value "TR2," the user does not need to withdraw the CVC **100**, and the decision in decision block **540** is "NO." Then, the method **500** ends.

Alternatively, in block **536**, a D/R ratio may be calculated to determine the location of the tip **112** of the CVC **100**. The D/R ratio may include the ratio of the deflection value of the P wave detected by the distal anode/cathode pair **182** to the stored reference deflection value of the P wave detected in the proximal SVC. In particular embodiments, the D/R ratio may include the ratio of the deflection value of the P wave detected by the distal anode/cathode pair **182** to the reference deflection value of the P wave detected by the reference anode/cathode pair **184**. In embodiments that include a reference pair **184**, the reference pair **184** may be used to detect the P wave in the proximal SVC. Because the distal anode/cathode pair **182** is inside the right atrium, the deflection value of its P wave is greater than or equal to about four times to about eight times the deflection value of the P wave observed in the proximal SVC.

When D/R ratio is equal to or greater than a threshold value "TR3" within a range of about 4.0 to about 8.0, the user or operator should withdraw the CVC **100**. By way of a non-limiting example, the threshold value "TR3" may be about 4.0. By way of a non-limiting example, the threshold value "TR3" may be equal to the predetermined maximum threshold value "TR1." Alternatively, the threshold value "TR3" could be set equal the largest D/R ratio observed thus far. Under these circumstances, in decision block **540**, the threshold value "TR3" may be used to determine whether the user or operator should withdraw the CVC **100**, i.e., if the D/R ratio exceeds the threshold value "TR3," the decision in decision block **540** is "YES," and the CVC **100** is withdrawn in block **528**. Otherwise, if the D/R ratio does not exceed the threshold value "TR3," the user does not need to withdraw the CVC **100**, and the decision in decision block **540** is "NO." Then, the method **500** ends.

After the CVC **100** is withdrawn in block **528**, the method **500** may return to block **520** to recalculate the D/P ratio.

In method **500**, determining when to withdraw the CVC **100** is unaffected by wide anatomic variability between individual people because instead of using predetermined threshold deflection values, the D/P ratio, P/R ratio, and/or D/R ratio of deflection values obtained from each individual is used.

The following table summarizes the relationship between the location of the tip **112** of the CVC **100** and the deflection values of the P waves detected by the proximal and distal anode/cathode pairs **180** and **182**:

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TABLE 3

	Location of the distal anode/cathode pair 182			
	Proximal SVC	Right Atrium	Right Atrium	Right Ventricle
	Location of the proximal anode/cathode pair 180			
	Proximal SVC	Proximal SVC	Right Atrium	Right Atrium
D/P ratio: Ratio of the deflection value of the distal anode/cathode pair 182 to the deflection value of the proximal anode/cathode pair 180	≈1	≥TR1	≈1	≤TMIN
P/R ratio: Ratio of the deflection value of the P wave detected by the proximal anode/cathode pair 180 and the deflection value of the P wave detected in the proximal SVC	≈1	≈1	≥TR2	≥TR2
D/R ratio: Ratio of the deflection value of the P wave detected by the distal anode/cathode pair 182 and the deflection value of the P wave detected in the proximal SVC	≈1	≥TR3	≥TR3	≈1

As mentioned above, each of the threshold values “TR1,” “TR2,” and “TR3” in Table 3 may be within a range of about 4.0 to about 8.0 and the minimum threshold value “TMIN” may be about 0.5. Alternatively, the threshold values “TR1,” “TR2,” and “TR3” in Table 3 may be set equal the largest D/R ratio observed during the performance of the method 500. By way of another example, the threshold values “TR1,” “TR2,” and “TR3” in Table 3 may be set equal the largest D/R ratio observed for the patient during the performance of any of the methods described herein and recorded for use with the method 500. While exemplary threshold values “TR1,” “TR2,” “TR3,” and “TMIN” have been provided for use as a general guideline, those of ordinary skill in the art appreciate that these values may benefit from adjustment as additional anatomic or electrophysiologic data is acquired and such modified values are within the scope of the present invention.

As is apparent from Table 3, either of the P/R ratio and the D/R ratio may be calculated first and used instead of the D/P ratio. For example, if the P/R ratio is calculated first, it may be compared to the threshold value “TR2.” If the P/R ratio is greater than or equal to the threshold value “TR2,” the tip 112 is in the right atrium or right ventricle and should be withdrawn. If the P/R ratio is less than the threshold value “TR2,” the tip 112 is in the right atrium or proximal SVC. When this occurs, either the D/P ratio or the D/R ratio may be calculated. If the D/P ratio is calculated, it may be compared to the predetermined maximum threshold value “TR1.” If the D/P ratio is greater than or equal to the predetermined maximum threshold value “TR1,” the tip 112 should be withdrawn. If the D/R ratio is calculated, it may be compared to the threshold value “TR3.” If the D/R ratio is greater than or equal to the threshold value “TR3,” the tip 112 should be withdrawn.

Alternatively, if the D/R ratio is calculated first, it may be compared to the threshold value “TR3.” If the D/R ratio is greater than or equal to the threshold value “TR3,” the tip 112 is in the right atrium and should be withdrawn. If the D/R ratio is less than the threshold value “TR3,” the tip 112 is in the

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right ventricle or proximal SVC. When this occurs, either the D/P ratio or the P/R ratio may be calculated. If the D/P ratio is calculated, it may be compared to the predetermined minimum threshold value “TMIN.” If the D/P ratio is less than or equal to the predetermined minimum threshold value “TMIN,” the tip 112 should be withdrawn. If the P/R ratio is calculated, it may be compared to the threshold value “TR2.” If the P/R ratio is greater than or equal to the threshold value “TR2,” the tip 112 should be withdrawn.

In addition to using the method 500 to determine when to withdraw the CVC 100, the QRS complex portion of the ECG waveforms detected by the distal anode/cathode pair 182 and/or the proximal anode/cathode pair 180 may be used to determine when the tip 112 of the CVC 100 is in the right atrium. Specifically, the tip 112 should be withdrawn because it is in the right atrium when the deflection value of the P wave detected by either the distal anode/cathode pair 182 or the proximal anode/cathode pair 180 is approximately equivalent to or greater than the voltage (or deflection value) of the QRS complex detected simultaneously by the same anode/cathode pair. The P wave and QRS complex typically look similar and deflect in the same direction. The CVC 100 may be advanced until the deflection value of the P wave is slightly less than or approximately equal to the deflection value of the QRS complex.

Further, a positive/total deflection ratio of the largest positive deflection value (of an initial positive or upwardly deflecting portion preceding a downwardly deflecting portion of a P wave detected by the distal anode/cathode pair 182 and/or the proximal anode/cathode pair 180) to the total deflection value (of the P wave detected by the distal anode/cathode pair 182 and/or the proximal anode/cathode pair 180) may be used to determine when the tip 112 of the CVC 100 is in the right atrium. As discussed above, the P wave voltage is almost entirely negative at the top of the right atrium (see trace 3 of FIG. 2B), biphasic in the mid right atrium (see trace 4 of FIG. 2B), and positive at the bottom of the right atrium (see trace 5 of FIG. 2B). Thus, advancement of the tip 112 may be halted when the positive/total deflection ratio is greater than a predetermined fraction (e.g., one quarter, one eighth, etc.). As mentioned above, with respect to the single electrode pair embodiments, when the positive/total deflection ratio exceeds the predetermined fraction, the tip 112 is in the right atrium.

As is apparent to those of ordinary skill, the proximal and distal anode/cathode pairs 180 and 182 may be used to detect the instantaneous location of the tip 112. Therefore, if the tip 112 migrates into the atrium or ventricle, this movement may be detected immediately. Following such an occurrence, a medical professional may be alerted via a signal, such as an alarm, and the like, to reposition the tip 112.

If the tip 112 is determined to be in the atrium, the method 190 described above may be used to determine the position of the tip 112 inside the atrium. Specifically, the electrode 114B (see FIG. 3A) may be attached to the skin of the patient. Then, the method 190 may be used to determine a positive/negative deflection ratio for the P wave detected by the electrode 114B and one of the electrodes 154 and 156 of the distal anode/cathode pair 182. The positive/negative deflection ratio may be compared to the first and second threshold values (see Table 2) and the location of the tip 112 within the atrium determined. Alternatively, instead of attaching the electrode 114B to the skin of the patient, one of the electrodes 157 and 158 of the reference anode/cathode pair 184 may be used. In such embodiments, the positive/negative deflection ratio is determined for the P wave detected by one of the electrodes 157 and 158 of the reference anode/cathode pair 184 and one

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of the electrodes **154** and **156** of the distal anode/cathode pair **182**. As mentioned above, it may be desirable to use the most distal electrode **156** of the distal anode/cathode pair **182**. The positive/negative deflection ratio may be compared to the first and second threshold values (see Table 2) and the location of the tip **112** within the atrium determined.

Because the voltage across each of the anode/cathode pairs **180** and **182** may vary depending over time, the voltage across wires **164** and **166** and wires **160** and **162** may each constitute a time-varying signal that can be analyzed using standard signal processing methods well known in the art. In a typical patient, the maximum of voltage across the anode/cathode pairs **180** and **182** may range from about 0.2 mV to about 3 mV. The signal from each anode/cathode pairs **180** and **182** may be amplified and/or filtered to improve the signal quality. A distal signal may be detected by the distal anode/cathode pair **182** and a proximal signal may be detected by the proximal anode/cathode pair **180**. Similarly, an optional reference signal may be detected by the reference anode/cathode pair **184**.

A separate ECG trace may be constructed for distal and proximal signals. In some embodiments, an ECG trace may also be constructed for the reference signal. The P wave portion of one or more of these ECG traces may be identified and analyzed. For example, the ECG trace of the distal signal may be visualized by connecting wires **164** and **166** of the distal anode/cathode pair **182** to a device such as a PACERVIEW® signal conditioner designed specifically to construct and display an ECG trace from a time varying low voltage signal. Similarly, the ECG trace of the proximal signal may be viewed by connecting the wires **160** and **162** of the proximal anode/cathode pair **180** to a PACERVIEW® signal conditioner. The ECG trace of the reference signal may be viewed by connecting the wires **167** and **168** of the proximal anode/cathode pair **184** to a PACERVIEW® signal conditioner.

In particular embodiments, each of the four wires **160**, **162**, **164**, and **166** may be coupled to a signal analysis system for analysis of the voltage information detected by the electrodes **150**, **152**, **154**, and **156**, respectively. In embodiments including electrodes **157** and **158**, the wires **167** and **168** may be coupled to the signal analysis system for analysis of the voltage information detected by the electrodes **157** and **158**, respectively. An exemplary signal analysis system **200** for analyzing the signals carried by wires **160**, **162**, **164**, and **166** and alerting the user or operator when to withdraw the tip **112** of the CVC **100** may be viewed in FIG. 7. In an alternate embodiment, the system **200** may also analyze the signals carried by wires **167** and **168**.

#### System 200

FIG. 8 is a block diagram of the components of the exemplary system **200**. The system **200** may include a programmable central processing unit (CPU) **210** which may be implemented by any known technology, such as a microprocessor, microcontroller, application-specific integrated circuit (ASIC), digital signal processor (DSP), or the like. The CPU **210** may be integrated into an electrical circuit, such as a conventional circuit board, that supplies power to the CPU **210**. The CPU **210** may include internal memory or memory **220** may be coupled thereto. The memory **220** may be coupled to the CPU **210** by an internal bus **264**.

The memory **220** may comprise random access memory (RAM) and read-only memory (ROM). The memory **220** contains instructions and data that control the operation of the CPU **210**. The memory **220** may also include a basic input/output system (BIOS), which contains the basic routines that

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help transfer information between elements within the system **200**. The present invention is not limited by the specific hardware component(s) used to implement the CPU **210** or memory **220** components of the system **200**.

All or a portion of the deflection values and/or deflection ratios calculated by the methods **140**, **190**, **450**, **500**, and **600**, including the reference deflection value, may be stored in the memory **220** for use by the methods.

Optionally, the memory **220** may include external or removable memory devices such as floppy disk drives and optical storage devices (e.g., CD-ROM, R/W CD-ROM, DVD, and the like). The system **200** may also include one or more I/O interfaces (not shown) such as a serial interface (e.g., RS-232, RS-432, and the like), an IEEE-488 interface, a universal serial bus (USB) interface, a parallel interface, and the like, for the communication with removable memory devices such as flash memory drives, external floppy disk drives, and the like.

The system **200** may also include a user interface **240** such as a standard computer monitor, LCD, colored lights **242** (see FIG. 7), PACERVIEW® signal conditioner, ECG trace display device **244** (see FIG. 7), or other visual display including a bedside display. In particular embodiments, a monitor or handheld LCD display may provide an image of a heart and a visual representation of the estimated location of the tip **112** of the CVC **100**. The user interface **240** may also include an audio system capable of playing an audible signal. In particular embodiments, the user interface **240** includes a red light indicating the CVC **100** should be withdrawn and a green light indicating the CVC **100** may be advanced. In another embodiment, the user interface **240** includes an ECG trace display device **244** capable of displaying the ECG trace of the distal and proximal signals. In the embodiment depicted in FIG. 7, the user interface **240** includes a pair of lights **242**, one red and the other green, connected in series with a ECG trace display device **244**. In some embodiments, a display driver may provide an interface between the CPU **210** and the user interface **240**. Because an ultrasound machine is typically used when placing peripherally inserted central catheters ("PICC" lines), the system **200** may be incorporated into an ultrasound unit (not shown).

The user interface **240** may permit the user to enter control commands into the system **200**. For example, the user may command the system **200** to store information such as the deflection value of the P wave inside the SVC. The user may also use the user interface **240** to identify which portion of the ECG trace corresponds to the P wave. The user interface **240** may also allow the user or operator to enter patient information and/or annotate the data displayed by user interface **240** and/or stored in memory **220** by the CPU **210**. The user interface **240** may include a standard keyboard, mouse, track ball, buttons, touch sensitive screen, wireless user input device and the like. The user interface **240** may be coupled to the CPU **210** by an internal bus **268**.

Optionally, the system **200** may also include an antenna or other signal receiving device (not shown) such as an optical sensor for receiving a command signal such as a radio frequency (RF) or optical signal from a wireless user interface device such as a remote control. The system **200** may also include software components for interpreting the command signal and executing control commands included in the command signal. These software components may be stored in memory **220**.

The system **200** includes an input signal interface **250** for receiving the distal and proximal signals. The input signal interface **250** may also be configured to receive the reference signal. The input signal interface **250** may include any stan-

standard electrical interface known in the art for connecting a double dipole lead wire to a conventional circuit board as well as any components capable of communicating a low voltage time varying signal from a pair of wires through an internal bus 262 to the CPU 210. The input signal interface 250 may include hardware components such as memory as well as standard signal processing components such as an analog to digital converter, amplifiers, filters, and the like.

The various components of the system 200 may be coupled together by the internal buses 262, 264, and 268. Each of the internal buses 262, 264, and 268 may be constructed using a data bus, control bus, power bus, I/O bus, and the like.

The system 200 may include instructions 300 executable by the CPU 210 for processing and/or analyzing the distal and/or proximal signals. These instructions may include computer readable software components or modules stored in the memory 220. In particular embodiments, the instructions 300 include instructions for performing the method 500 (see FIG. 10).

The instructions 300 may include an ECG Trace Generator Module 310 that generates a traditional ECG trace from the distal and/or proximal signals. In some embodiments, the ECG Trace Generator Module 310 may generate a traditional ECG trace from the reference signal. As is appreciated by those of ordinary skill in the art, generating an ECG trace from an analog signal, such as the distal and proximal signals, may require digital or analog hardware components, such as an analog to digital converter, amplifiers, filters, and the like and such embodiments are within the scope of the present invention. In particular embodiments, some or all of these components may be included in the input signal interface 250. In an alternate embodiment, some or all of these components may be implemented by software instructions included in the ECG Trace Generator Module 310. The ECG Trace Generator 310 may include any method known in the art for generating an ECG trace from a time varying voltage signal.

The ECG Trace Generator 310 may record one or more of the ECG traces generated. Presently, a chest x-ray is used to document the location of the tip 112. This documentation may be used to prove the tip 112 of the CVC was placed correctly. Using the present techniques, the recorded ECG trace(s) may be used in addition to or instead of the chest x-ray to document tip 112 location. For example, the recorded ECG trace(s) may demonstrate that the tip 112 has migrated from the proximal SVC into the right atrium. Further, the recorded ECG trace(s) could document the repositioning of the tip 112 back into proximal SVC. Additionally, the recorded ECG trace(s) could document that the tip 112 was initially placed correctly and did not migrate from its initial position. In this manner, the ECG trace(s) could be used to document the correct or incorrect placement of the tip 112 and could be included in the patient's medical record, replacing or supplementing the prior art chest x-ray. Further, if the tip 112 does migrate, the recorded ECG trace(s) could be used to determine whether the tip entered the atrium, how far into the atrium the tip migrated, and/or whether the tip entered the ventricle.

The instructions 300 may include a P Wave Detection Module 320 for detecting or identifying the P wave portion of the ECG trace. The P wave portion of the ECG trace may be detected using any method known in the art. In particular embodiments, the P Wave Detection Module 320 receives input from the user or operator via the user interface 240. The input received may identify the P wave portion of the ECG trace. Optionally, the P Wave Detection Module 320 may include instructions for identifying the QRS complex as well as the P wave portion of the ECG trace. Further, the P Wave

Detection Module 320 may include instructions for determining a deflection value for an initial upwardly deflecting portion of a single P wave preceding a downwardly deflecting portion. The P Wave Detection Module 320 may also include instructions for determining a positive/total deflection ratio of the largest positive deflection value for the initial upwardly deflecting portion of the P wave to the deflection value for the entire P wave.

The instructions 300 may include an Interpretive Module 330 for comparing the P wave generated for the distal, proximal, and/or reference signals. In particular embodiments, the Interpretive Module 330 determines the deflection value of the P wave generated for the distal and/or proximal signals. In some embodiments, the Interpretive Module 330 determines the deflection value of the P wave generated for the reference signal. The Interpretive Module 330 may direct the CPU 210 to store the deflection value of the distal, proximal, and/or reference signals in memory 220. In particular, it may be desirable to store the deflection value of the P wave encountered in the proximal SVC. The Interpretive Module 330 may receive input from the user or operator via the user interface 240 instructing the Interpretive Module 330 to store the deflection value. This information could be stored under a unique patient identifier such as a medical record number so that tip location information could be accessed anytime during the life of the CVC 100, potentially avoiding the need for a chest x-ray to document current location.

With respect to performing the method 500 illustrated in FIG. 10, the Interpretive Module 330 may also determine the D/P ratio by calculating the ratio of the deflection value of the distal signal to the deflection value of the proximal signal. If the D/P ratio is approximately equal to or greater than the maximum threshold value "TR1," the tip 112 of the CVC 100 may be in the right atrium. The Interpretive Module 330 may alert the user or operator that the tip 112 is in the right atrium and the CVC 100 should be withdrawn from the right atrium. On the other hand, if the D/P ratio is approximately equal to or less than the minimum threshold value "TMIN," the tip 112 of the CVC 100 may be in the right ventricle. The Interpretive Module 330 may alert the user or operator that the tip 112 is in the right ventricle and the CVC 100 should be withdrawn therefrom.

If the D/P ratio is less than the maximum threshold value "TR1" and greater than the minimum threshold value "TMIN," the tip 112 may be in either the right atrium or the proximal SVC. When this happens, the Interpretive Module 330 may calculate the P/R ratio and/or the D/R ratio. For example, if the D/R ratio is approximately equal to or greater than the threshold value "TR3," the tip may be in the right atrium and should be withdrawn therefrom. When this occurs, the Interpretive Module 330 may alert the user or operator that the tip 112 is in the right atrium. If the D/R ratio is approximately less than the threshold value "TR3," the tip 112 is in the SVC and may be advanced if the operator so chooses. The Interpretive Module 330 may communicate to the user or operator that the tip 112 may be advanced.

On the other hand, if the P/R ratio is approximately equal to or greater than the threshold value "TR2," the tip may be in the right atrium or right ventricle and should be withdrawn therefrom. When this occurs, the Interpretive Module 330 may alert the user or operator to withdraw the tip 112. If the P/R ratio is approximately less than the threshold value "TR2," the tip 112 is in the SVC (because the D/P ratio is less than the maximum threshold value "TR1") and may be advanced if the operator so chooses. The Interpretive Module 330 may communicate to the user or operator that the tip 112 may be advanced.



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In an alternate embodiment, the P/R ratio is used instead of the D/P ratio. Whenever the P/R ratio is approximately equal to or greater than the threshold value "TR2," the user or operator may be alerted to withdraw the CVC 100. If the P/R ratio is approximately less than the threshold value "TR2," the D/P ratio or D/R ratio may be calculated and used to determine the position of the tip 112 of the CVC 100.

In another alternate embodiment, the D/R ratio is used instead of the D/P ratio. Whenever the D/R ratio is approximately equal to or greater than the threshold value "TR3," the user or operator may be alerted to withdraw the CVC 100. If the D/R ratio is approximately less than the threshold value "TR3," the D/R ratio or P/R ratio may be calculated and used to determine the position of the tip 112 of the CVC 100.

In particular embodiments, the instructions in the Interpretive Module 330 direct the CPU 210 to use the user interface 240 to communicate whether the tip 112 should be withdrawn to the user. The CPU 210 may use the user interface 240 to communicate the tip 112 may be advanced. Because the Interpretive Module 330 may interpret the P wave to obtain the deflection values of the distal and proximal signals, compare the deflection values, and provide the operator with immediate real-time feedback, the operator need not interpret the actual ECG waveforms.

#### Monitor 127

The monitor 127 of the system 121 for use with single pair of electrode embodiments will now be described. Returning to FIG. 3A, for illustrative purposes, the monitor 127 is described as coupled to each of the electrodes 114A and 114B by wires 123 and 129, respectively. However, in alternate embodiments, the monitor 127 is coupled to the electrodes 176 and 174 of the distal anode/cathode pair 182 (see FIG. 3B) by wires 123 and 129, respectively. By way of another alternate embodiment, one or both of the distal anode/cathode pair 182 may be coupled to the monitor 127 by wire 123 and one or both of the proximal anode/cathode pair 180 may be coupled to the monitor 127 by wire 129.

Referring to FIG. 9, the monitor 127 includes a signal analysis system 400 that may be substantially similar to the signal analysis system 200 described above. Specifically, the system 400 may construct an ECG trace for the electrical signals detected by the pair of electrodes 114, and identify and analyze the P wave portion of the ECG trace using any method discussed above with respect to the system 200. Further, the system 400 is configured to display information to the user or operator communicating the current position of the tip 112 of the CVC 100.

Like reference numerals are used to identify substantially identical components in FIGS. 8 and 9. The system 400 includes the CPU 210, the memory 220, the input signal interface 250 for receiving the signals detected by the pair of electrodes 114, and a user interface 410. Like system 200, the various components of the system 400 may be coupled together by the internal buses 262, 264, and 268.

All or a portion of the deflection values and/or deflection ratios calculated by the methods 140, 190, 450, and 600, including the reference deflection value, may be stored in the memory 220 for use by the methods.

The system 400 differs from the system 200 with respect to the user interface 410 and at least a portion of the computer-executable instructions stored in memory 220. Returning to FIG. 3A, in some embodiments, the user interface 410 includes an array of lights 412, a first portion 412A of which corresponds to ratio values below or equal to the first predefined threshold value of the method 140 (see FIG. 4), a

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second portion 412B of which corresponds to the range of ratio values greater than the first predefined threshold value and less than or equal to the second threshold value of the method 140, and a third portion 412C of which indicates the second predefined threshold value has been exceeded.

By way of a non-limiting example, the first portion 412A may include an array of green lights. The number of green lights lit may indicate the magnitude of the ratio of the deflection value of the currently observed P wave to the reference deflection value. For example, the first portion may include eight lights. The first light may indicate the ratio is less than or equal to 0.8. For each 0.2 increase in the ratio, another green light may be lit until all eight green lights are lit and the ratio is approximately equal to 4.0. If the ratio decreases to less than 4.0, for each 0.2 decrease in the ratio, a green light may be turned off until only a single green light is lit.

By way of a non-limiting example, the second portion of lights may include an array of yellow lights. The number of yellow lights lit may indicate the magnitude of the ratio of the deflection value of the currently observed P wave to the reference deflection value. For example, the second portion may include eight yellow lights. The first yellow light may indicate the ratio is approximately equal to about 4.4 to about 4.5. For each 0.2 increase in the ratio above 4.4, another yellow light may be lit until all eight yellow lights are lit and the ratio is approximately equal to 6.0. If the ratio decreases to less than 6.0, for each 0.2 decrease in the ratio, a yellow light may be turned off until the ratio is less than 4.4 and none of the yellow lights are lit.

By way of a non-limiting example, the third portion may include a single red light indicating the magnitude of the ratio of the deflection value of the currently observed P wave to the reference deflection value has exceeded 6.0. If the ratio decreases to less than 6.0, the red light may be turned off. In this manner, the user interface 410 provides greater resolution for ratio values less than or equal to the first predefined threshold value than for ratio values between the first and second predefined threshold values.

While the above example has been described as including lights (such as LEDs, conventional light bulbs, and the like), those of ordinary skill in the art appreciate that any indicator may be used and such embodiments are within the scope of the present teachings. For example, a monitor displaying a graphical representation of lights, a figure, such as a bar, that increases or decreases in size to reflect an increase or decrease in the ratio, and the like may be used in place of the array of lights. Optionally, the user interface 410 may include a screen 420 (see FIG. 3A) configured to display information to the user or operator. For example, the screen 420 may display an image of a heart and a visual representation of the estimated location of the tip 112 of the CVC 100. Alternatively, the screen 420 may display the words "ADVANCE," "HOLD," or "WITHDRAW" as appropriate.

The user interface 410 may also indicate when the tip 112 is located in the ventricle. By way of a non-limiting example, the user interface 410 may include a light, audio signal, or other indicator configured to indicate the tip 112 has entered the ventricle.

In some embodiments, a display driver may provide an interface between the CPU 210 and the user interface 410. Optionally, the user interface 410 includes an audio system capable of playing an audible signal. For example, the audio system may produce a tone that increases in pitch as the ratio increases and decreases in pitch as the ratio decreases may be used. Alternatively, the audio system may produce one tone when the ratio is greater than the first predefined threshold value, indicating the tip 112 should be withdrawn. In such

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embodiments, the audio system may produce another more urgent or annoying tone when the ratio is above the second predefined threshold value. Further, the audio system may be silent when the ratio is below the first predefined threshold value.

The user interface 410 may permit the user to enter control commands into the system 200. For example, the user may command the system 200 to store information such as the deflection value of the P wave inside the proximal SVC (e.g., the reference deflection value), atrium (e.g., the reference atrium deflection value), and the like. The user may also use the user interface 410 to identify manually which portion of the ECG trace corresponds to the P wave. The user interface 410 may also allow the user or operator to enter patient information (such as a patient identifier number) and/or annotate the data displayed by user interface 410 and/or stored in memory 220 by the CPU 210. The user interface 410 may include a standard keyboard, mouse, track ball, buttons 416, touch sensitive screen, wireless user input device and the like. The user interface 410 may be coupled to the CPU 210 by an internal bus 268.

By way of a non-limiting example, a patient's reference deflection value (detected when the tip 112 was located in the proximal SVC) and/or reference atrium deflection value (detected when the tip 112 was located in the atrium) could be stored in the memory 220 and associated with the patient's patient identifier number or some other identification number. In this manner, the patient's recorded reference deflection value could be used anytime during the life of the CVC 100 by recalling the reference deflection value from memory 220 using the patient's patient identifier number, which could be entered manually using the user interface 410.

Optionally, the system 400 may also include an antenna or other signal receiving device (not shown) such as an optical sensor for receiving a command signal such as a radio frequency (RF) or optical signal from a wireless user interface device such as a remote control. The system 400 may also include software components for interpreting the command signal and executing control commands included in the command signal. These software components may be stored in memory 220.

The system 400 includes instructions 300 executable by the CPU 210 for processing and/or analyzing the electrical signals detected by the pair of electrodes 114. The instructions 300 may include the ECG Trace Generator Module 310 that generates a traditional ECG trace from the signals detected by the pair of electrodes 114, the P Wave Detection Module 320 for detecting or identifying the P wave portion of the ECG trace, and the Interpretive Module 330. As discussed above with respect to the system 200, the ECG Trace Generator Module 310 may record the ECG trace generated thereby.

Optionally, the P Wave Detection Module 320 may include instructions for identifying the QRS complex as well as the P wave portion of the ECG trace. Further, the P Wave Detection Module 320 may include instructions for determining a deflection value for an initial upwardly deflecting portion of a single P wave preceding a downwardly deflecting portion. The P Wave Detection Module 320 may also include instructions for determining a positive/total deflection ratio of the largest positive deflection value for the initial upwardly deflecting portion of the P wave to the deflection value for the entire P wave.

Like the Interpretive Module 330 of the system 200, the Interpretive Module 330 of the system 400 determines the deflection value of the P wave detected by a pair of electrodes (i.e., the pair of electrodes 114). However, other functions performed by the Interpretive Module 330 may differ in sys-

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tem 400 from those performed by the Interpretive Module 330 in system 200. The Interpretive Module 330 directs the CPU 210 to store the deflection value of the P wave detected by the pair of electrodes 114 in the proximal SVC in memory 220. The Interpretive Module 330 may receive input from the user or operator via the user interface 410 instructing the Interpretive Module 330 to store the deflection value.

The Interpretive Module 330 also includes instructions for performing the method 140, 190, and/or the method 600. With respect to the method 140 (see FIG. 4), the Interpretive Module 330 may determine the ratio of the deflection value of the currently observed P wave to the reference deflection value. The Interpretive Module 330 may compare this ratio to the first predefined threshold (e.g., about 1.5). If the ratio is less than or equal to the first predefined threshold, the Interpretive Module 330 determines the tip 112 is in the SVC. Further, if the determination is made in block 143, the Interpretive Module 330 may signal the user or operator to advance the tip 112. If the determination is made in block 145, the Interpretive Module 330 may signal the user or operator to stop withdrawing the tip 112.

If the ratio is greater than the first predefined threshold, the Interpretive Module 330 determines the tip 112 is not in a desired location and instructs the user interface 410 to signal the user or operator to withdraw the tip.

The Interpretive Module 330 may compare the ratio to the second predefined threshold value (e.g., about 2.0). If the ratio is less than or equal to the second predefined threshold value, the Interpretive Module 330 determines the tip 112 is in the distal SVC near the SA node or in the atrium near the SA node. If the ratio is greater than the second predefined threshold value, the Interpretive Module 330 determines the tip 112 is in the atrium.

Optionally, the Interpretive Module 330 may determine the ratio of the deflection value of the current P wave detected by the pair of electrodes 114 to the reference atrium deflection value. The Interpretive Module 330 may compare this ratio to the third predefined threshold value (e.g., about 0.5) to determine whether the tip 112 is in the atrium or the ventricle.

With respect to the method 190 (see FIG. 6), the Interpretive Module 330 may determine the tip 112 is located within the right atrium using any method known in the art or disclosed herein. The Interpretive Module 330 then calculates the positive/negative deflection ratio and compares this ratio to the first predetermined threshold value (e.g., about 0.30). If the positive/negative deflection ratio is less than the first predetermined threshold value, the Interpretive Module 330 determines the tip 112 is in the upper right atrium. On the other hand, if the positive/negative deflection ratio is greater than or equal to the first predetermined threshold value, the Interpretive Module 330 compares positive/negative deflection ratio to the second predetermined threshold value (e.g., about 1.30). If the positive/negative deflection ratio is greater than the second predetermined threshold value, the Interpretive Module 330 determines the tip 112 is in the lower atrium. Otherwise, if the positive/negative deflection ratio is greater than or equal to the first predetermined threshold value and less than or equal to the second predetermined threshold value, the Interpretive Module 330 determines the tip 112 is in the mid atrium.

With respect to the method 600 (see FIGS. 11A and 11B), the Interpretive Module 330 may store a reference deflection value and determine the deflection ratio of the deflection value of the currently observed P wave to the reference deflection value. After the tip 112 is withdrawn or advanced, the Interpretive Module 330 may determine the current deflection ratio of the deflection value of the currently

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observed P wave to the reference deflection value. The deflection ratio determined before the tip 112 was withdrawn or advanced is stored by the Interpretive Module 330 as a previous deflection ratio.

Each time the tip 112 is moved (e.g., advanced or withdrawn), the Interpretive Module 330 determines whether the current deflection ratio is the largest observed since the CVC 100 was inserted into the venous system, and if the current deflection ratio is the largest deflection ratio observed, stores the current deflection ratio as the maximum deflection ratio.

The Interpretive Module 330 compares the current deflection ratio to the previous deflection ratio. If the current deflection ratio is less than or equal to the previous deflection ratio, the Interpretive Module 330 determines the tip 112 has been advanced too far and may signal the user to withdraw the CVC 100. Then, the Interpretive Module 330 determines whether the tip 112 has been withdrawn far enough. The Interpretive Module 330 may determine the tip 112 has been withdrawn far enough when the positive/total deflection ratio is less than a predetermined fraction (e.g., one quarter, one eighth, etc.). Otherwise, the tip 112 has not been withdrawn far enough. If the tip 112 has not been withdrawn far enough, the Interpretive Module 330 signals the user to withdraw the tip 112.

If the tip 112 has been withdrawn far enough, the Interpretive Module 330 determines whether the current deflection ratio is approximately equal to the maximum deflection ratio. If the current deflection ratio is not approximately equal to the maximum deflection ratio, the Interpretive Module 330 determines the tip 112 has been withdrawn too far and signals the user to advance the CVC 100.

As mentioned above, the Interpretive Module 330 may compare current deflection ratio to the previous deflection ratio. If the current deflection ratio is greater than the previous deflection ratio, the Interpretive Module 330 determines whether the current deflection ratio is less than a maximum threshold value (e.g., 8.0). If the current deflection ratio is less than the maximum threshold value, the Interpretive Module 330 determines the tip 112 has not been advanced far enough and signals the user to advance the CVC 100.

If instead the current deflection ratio is greater than or equal to the maximum threshold value, the Interpretive Module 330 determines whether the current deflection ratio is approximately equal to the maximum threshold value. If the current deflection ratio is not approximately equal to the maximum threshold value, the Interpretive Module 330 determines the tip 112 has been advanced too far and signals the user to withdraw the CVC 100. After the tip 112 is withdrawn, the Interpretive Module 330 determines whether the current deflection ratio is approximately equal to the maximum threshold value.

If the current deflection ratio is not approximately equal to the maximum threshold value, the Interpretive Module 330 determines whether the current deflection ratio is less than the maximum threshold value (indicating the tip 112 has been withdrawn too far). If the current deflection ratio is less than the maximum threshold value, the Interpretive Module 330 determines the tip 112 has been withdrawn too far and signals the user to advance the CVC 100. On the other hand, if the current deflection ratio is still greater than the maximum threshold value, the Interpretive Module 330 determines the tip 112 has not been withdrawn far enough and signals the user to withdraw the CVC 100.

Optionally, whenever the current deflection ratio is approximately equal to the maximum deflection ratio or the

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maximum threshold value, the Interpretive Module 330 may signal the user to stop moving (e.g., advancing or withdrawing) the CVC 100.

With respect to the methods 140, 190, and 600, the instructions in the Interpretive Module 330 direct the CPU 210 to use the user interface 410 to communicate whether the tip 112 should be withdrawn to the user. Further, the instructions in the Interpretive Module 330 direct the CPU 210 to use the user interface 410 to communicate the tip 112 may be advanced. Because the Interpretive Module 330 may interpret the P wave to obtain the deflection values, compare the deflection values, and provide the operator with immediate real-time feedback, the operator need not interpret the actual ECG waveforms.

Optionally, the system 400 could be coupled to a prior art navigational system, such as a VIASYS MedSystems NAVIGATOR® BioNavigation® system, manufactured by VIASYS Healthcare Inc. of Conshohocken, Pa., which is principally used to guide peripherally placed lines, such as a peripherally inserted central catheter ("PICC"). Such systems determine the location of a PICC line using magnetic fields that are generated by a detector, and detected by a magnetically activated position sensor located in the tip of a stylet inserted inside the PICC near its tip. By way of a non-limiting example, the detector may include a NAVIGATOR® electronic locating instrument configured to emit low-level, high-frequency magnetic fields. Also by way of a non-limiting example, the stylet may include a MAPCath® Sensor Stylet also manufactured by VIASYS Healthcare Inc.

The sensor in the tip of the stylet is activated by the magnetic field emitted by the detector. The sensor is operable to output its location via a wire coupled to the sensor and extending longitudinally along the PICC to the detector, which is configured to interpret the signal and communicate the location of the tip to the user or operator. As mentioned above, because such navigational systems depend upon a relationship between surface landmarks and anatomic locations, they cannot be used to determine the location of the tip 112 of the CVC 100 with sufficient accuracy. However, the system 400 may be used, in conjunction with a navigational system to improve the accuracy of the navigational system.

By way of non-limiting examples, additional prior art navigational systems include the Sherlock Tip Location System used with the stylet provided in Bard Access Systems PICC kits both of which are manufactured by C. R. Bard, Inc. of Salt Lake City, Utah, the CathRite™ system manufactured by Micronix Pty. Ltd. of Australia, and the like. As is apparent to those of ordinary skill in the art, the present teaching may be combined with one or more of these additional exemplary navigational systems and used to improve the accuracy of those systems.

In further embodiments, the teachings provided herein may be expanded to use electrophysiology procedures for navigating other bodily channels. For example, in the prior art, ECG guidance techniques have been used to place feeding tubes. Because the QRS complex measured in the stomach is upright but in a post pyloric area (first part of the duodenum, beyond the stomach) the QRS complex is down-going, one or more threshold deflection values may be determined and used to determine the placement of the tip of the feeding tube.

The foregoing described embodiments depict different components contained within, or connected with, different other components. It is to be understood that such depicted architectures are merely exemplary, and that in fact many other architectures can be implemented which achieve the same functionality. In a conceptual sense, any arrangement of components to achieve the same functionality is effectively

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“associated” such that the desired functionality is achieved. Hence, any two components herein combined to achieve a particular functionality can be seen as “associated with” each other such that the desired functionality is achieved, irrespective of architectures or intermedial components. Likewise, any two components so associated can also be viewed as being “operably connected”, or “operably coupled”, to each other to achieve the desired functionality.

While particular embodiments of the present invention have been shown and described, it will be obvious to those skilled in the art that, based upon the teachings herein, changes and modifications may be made without departing from this invention and its broader aspects and, therefore, the appended claims are to encompass within their scope all such changes and modifications as are within the true spirit and scope of this invention. Furthermore, it is to be understood that the invention is solely defined by the appended claims. It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as “open” terms (e.g., the term “including” should be interpreted as “including but not limited to,” the term “having” should be interpreted as “having at least,” the term “includes” should be interpreted as “includes but is not limited to,” etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example, as an aid to understanding, the following appended claims may contain usage of the introductory phrases “at least one” and “one or more” to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles “a” or “an” limits any particular claim containing such introduced claim recitation to inventions containing only one such recitation, even when the same claim includes the introductory phrases “one or more” or “at least one” and indefinite articles such as “a” or “an” (e.g., “a” and/or “an” should typically be interpreted to mean “at least one” or “one or more”); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation is explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean at least the recited number (e.g., the bare recitation of “two recitations,” without other modifiers, typically means at least two recitations, or two or more recitations).

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Accordingly, the invention is not limited except as by the appended claims.

The invention claimed is:

1. A monitor electrically couplable to an electrode attached to a tip of a central venous catheter that is insertable into a venous system of a subject, the monitor comprising:

a processor;  
a withdraw indicator coupled to the processor configured to indicate when the tip of the central venous catheter should be withdrawn; and  
a memory coupled to the processor and having instructions executable by the processor, when executed, the instructions instructing the processor to:  
store an identifier identifying the subject,  
determine and store a reference deflection value of a P wave detected by the electrode attached to the tip of the central venous catheter,  
associate the reference deflection value with the identifier identifying the subject,  
determine a current deflection value of a current P wave detected by the electrode attached to the tip of the central venous catheter,  
calculate a current ratio of the current deflection value to the stored reference deflection value, and  
actuate the withdraw indicator to indicate the tip of the central venous catheter should be withdrawn based on the current ratio.

2. The monitor of claim 1, wherein the instructions executable by the processor further instruct the processor to:

store a maximum ratio comprising a largest ratio of the current deflection value to the stored reference deflection value calculated for the subject,  
associate the maximum ratio with the identifier identifying the subject,  
compare the current ratio to the maximum ratio, and  
actuate the withdraw indicator to indicate the tip of the central venous catheter should be withdrawn based on the comparison.

3. The monitor of claim 1, wherein the instructions executable by the processor further instruct the processor to compare the current ratio to a threshold value and actuate the withdraw indicator to indicate the tip of the central venous catheter should be withdrawn based on the comparison.

4. The monitor of claim 1, wherein the instructions executable by the processor further instruct the processor to store at least one of the current deflection value and the current ratio.

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